5G Networks and Beyond

(Day 2. Enhanced Mobile Broadband)

2023년 4월
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- Day 1: 5G 네트워크 개요
- Day 2: Enhanced Mobile Broadband
- Day 3: Private 5G와 테스트베드
- Day 4: 5G 네트워크 인프라 가상화 기술
- Day 5: Cloud Native 5G 인프라
- (별도) Day 4~5 실습교재

➢ Day 2: Enhanced Mobile Broadband

- Review Day 1
- NR 과 Access Network
- 5G Access Network 구조
- 5G Spectrum 기술
- 5G Network Slicing

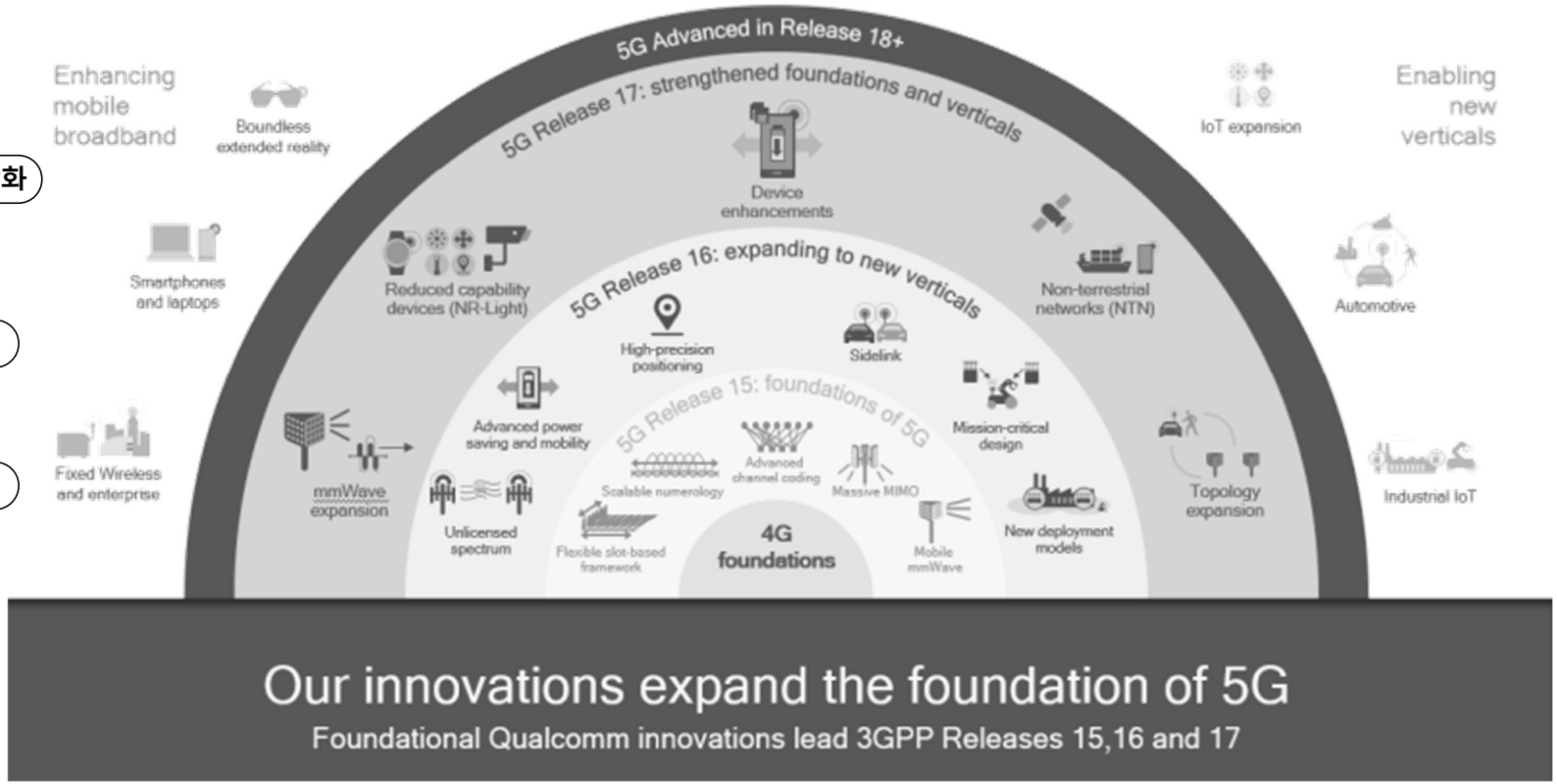
DAY 2: ENHANCED MOBILE BROADBAND

❖ **3GPP standards 3GPP Rel, 15, 16, 17** (기술과 시장 확대 강화)

Rel. 17 기술/시장 확대 강화

Rel. 16 시장 확대

Rel 15. 기반 기술



Source: 퀄컴

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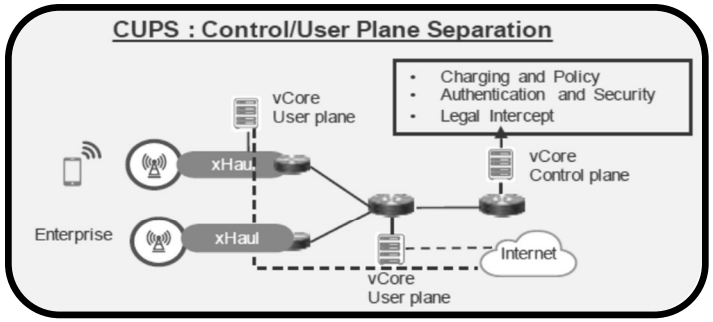
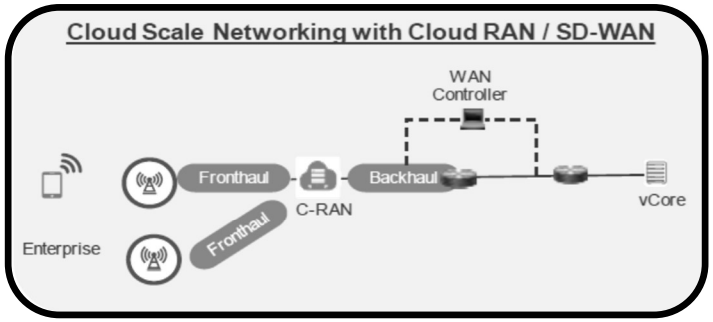
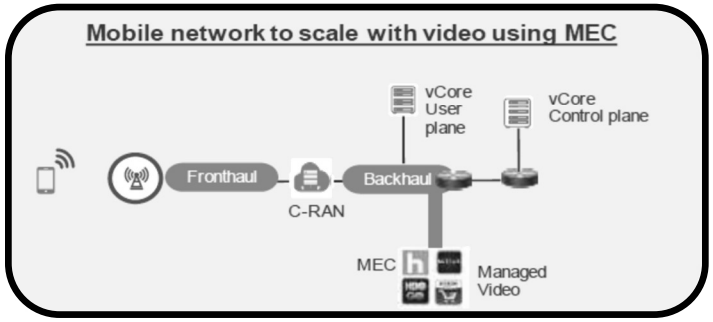
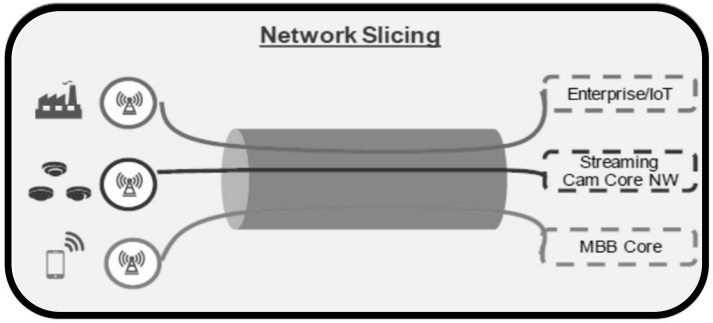
❖ **5G Enabling Technologies:**

- **CUPS** (제어/사용자 플레인 분리)
- **Cloud Scale** (클라우드 스케일)
- **MEC** (모바일 에지 컴퓨팅)
- **Network Slicing**









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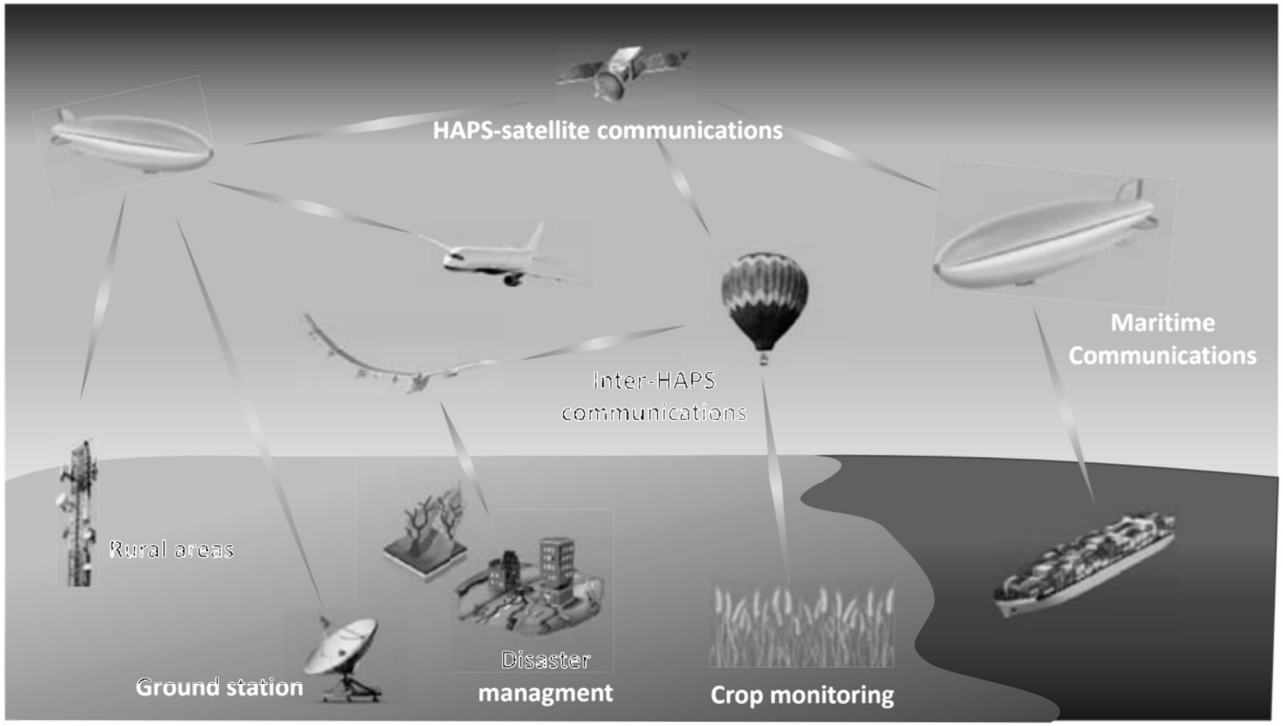
❖ **NTN: High-altitude platform stations (HAPSs)**

- **Examples of several scenarios where HAPSs can be exploited.**



Source: Antenna Design for 5G and Beyond, Printed Edition of the Special Issue Published in Sensors, Naser Ojaroudi Parchin (www.mdpi.com/journal/sensors)

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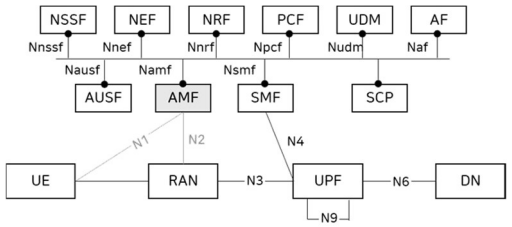
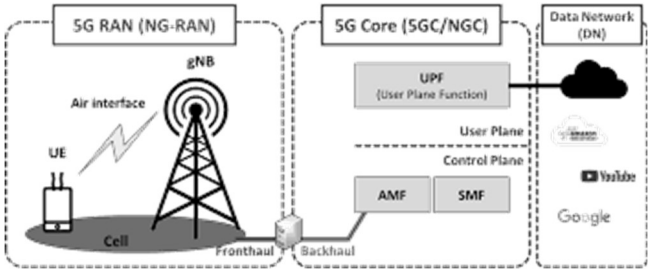
❖ **5세대 이동통신 핵심망, 五世代移動通信核心網, 5th Generation Core Network, 5GC**

- **AMF** (Access and Mobility management Function): **접속과 이동성 관리 기능**
- **SMF** (Session Management Function): **세션 관리 기능**
- **UPF** (User Plane Function): **사용자 평면 기능**
- **PCF** (Policy Control Function): **정책 제어 기능**
- **AUSF** (Authentication Server Function): **인증 서버 기능**
- **UDM** (Unified Data Management): **통합 데이터 관리**
- **AF** (Application Function): **응용 기능**
- **NEF** (Network Exposure function): **네트워크 노출 기능**
- **NRF** (Network Repository Function): **네트워크 저장소 기능**
- **NSSF** (Network Slice Selection Function): **네트워크 슬라이스 선택 기능**





https://jb-story.tistory.com/346

Source: http://terms.tta.or.kr/dictionary/dictionaryView.do?word_seq=171377-2

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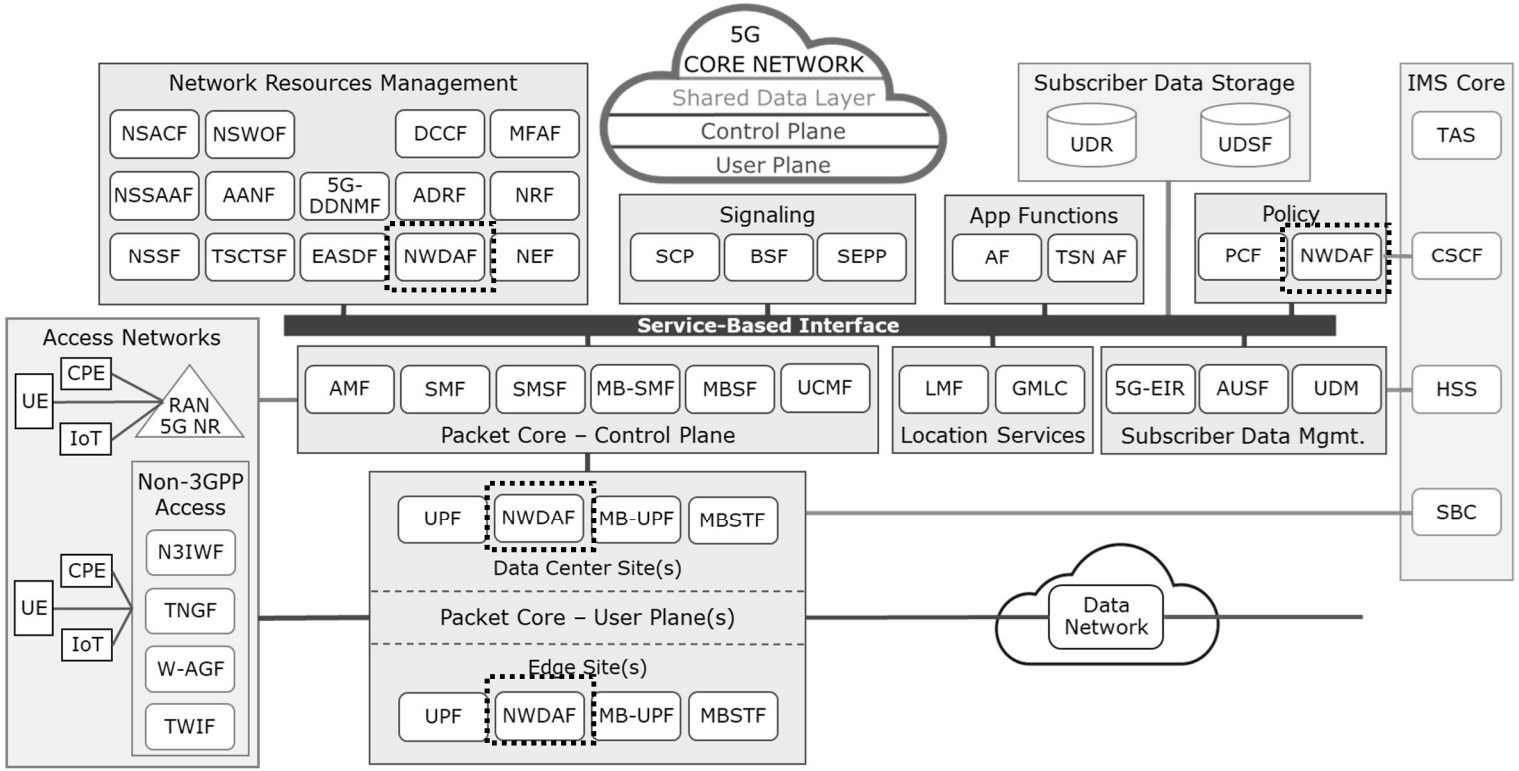
❖ 5G Core Cloud-Native Service-Based Architecture (SBA)



Source: Dell'Oro Group and 3GPP (**NWDAF**: NetWork Data Analytics Function), 네트워크 데이터 분석 기능

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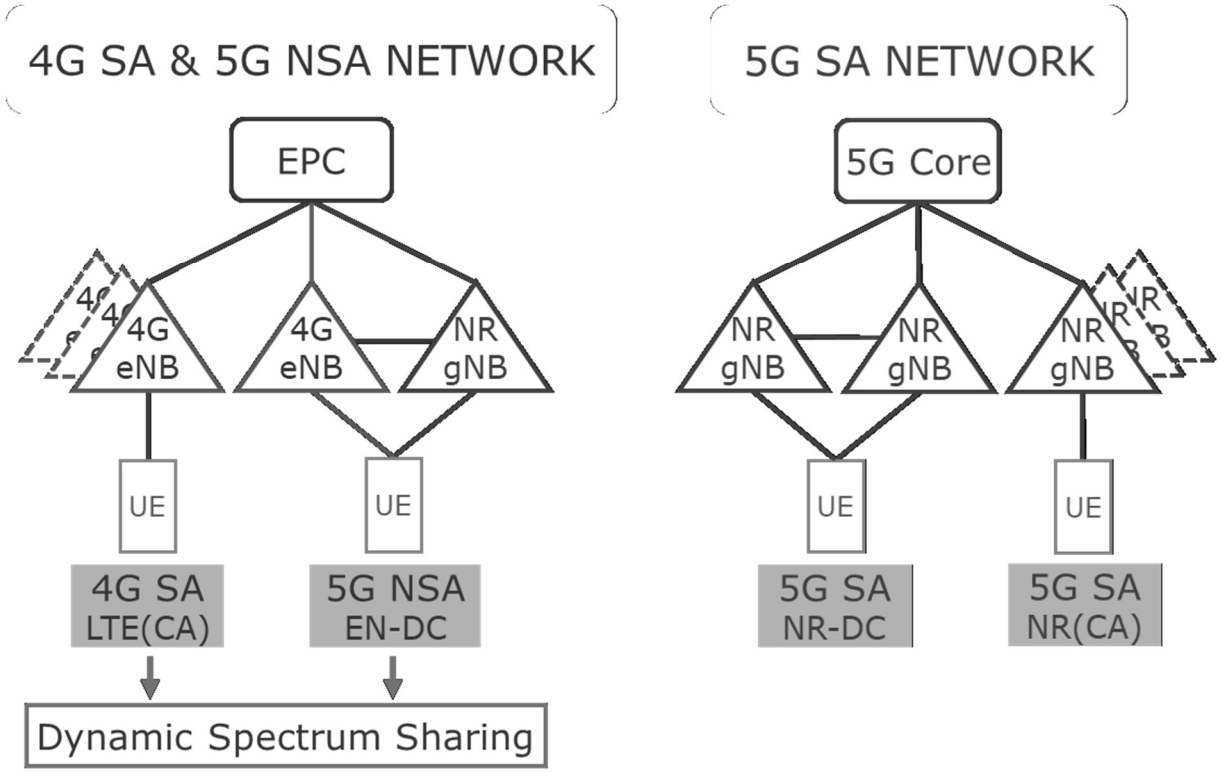
❖ **The route from 4G SA/5G NSA to 5G SA**



Source: Dell'Oro Group

Carrier Aggregation (CA)

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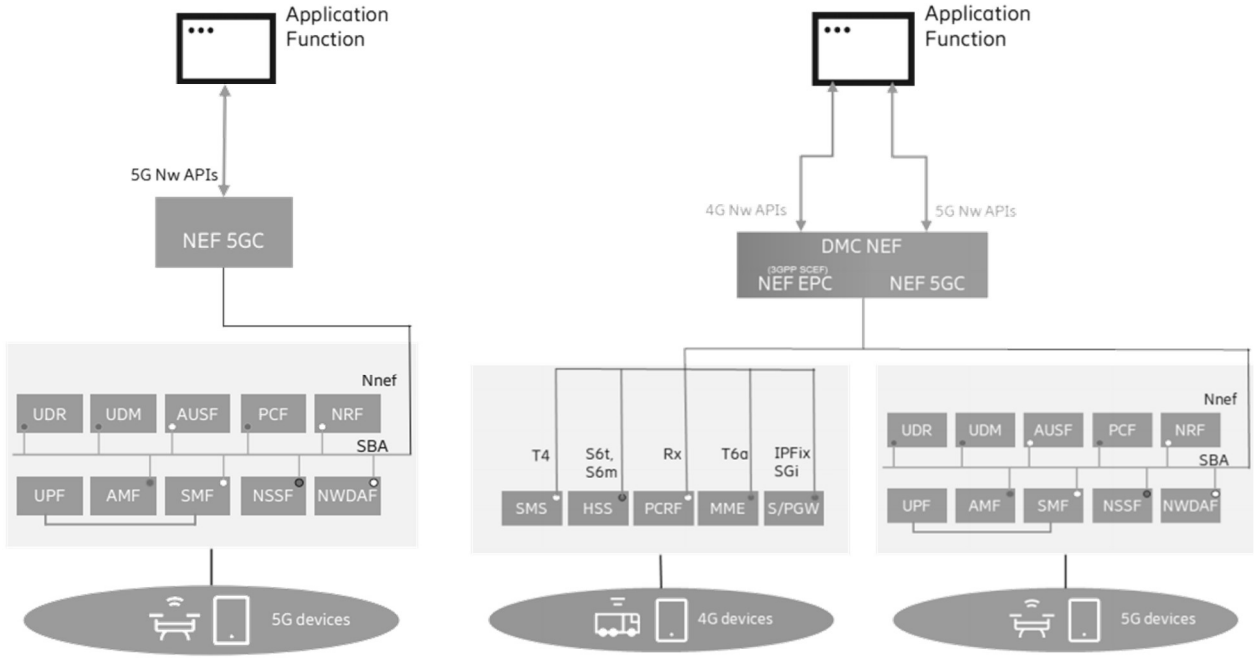
❖ NEF: Network Exposure Function

- 네트워크 프로그래밍 허용
- 보안 도입
- 액세스 제어
- SLA 적용
- 네트워크 복잡성 숨기기
- API 조화
- 새로운 수익원 창출
- 새로운 비즈니스 모델 활성화



Source: Dell'Oro Group

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❖ 36개 MNO가 5G SA eMBB 서비스를 공개 출시

Region	2020	2021	2022
North America	T-Mobile – USA	Rogers – Canada	AT&T Wireless – USA DISH Wireless – USA Verizon – USA
EMEA	Rain – South Africa	Telefónica – Germany Vodafone – Germany stc – Kuwait Zain – Saudi Arabia Vodafone – UK	stc– Bahrain Telekom – Germany
APAC	China Mobile China Mobile – HK China Telecom China Unicom AIS – Thailand TOT – Thailand True – Thailand	TPG Telecom – Australia NTT DOCOMO – Japan Softbank – Japan Smart – Philippines M1 – Singapore SingTel – Singapore StarHub – Singapore KT – South Korea Taiwan Mobile	Optus – Australia China Broadnet KDDI – Japan
CALA			Claro – Brazil TIM – Brazil Vivo – Brazil

Source: Dell'Oro Group, as November 2022

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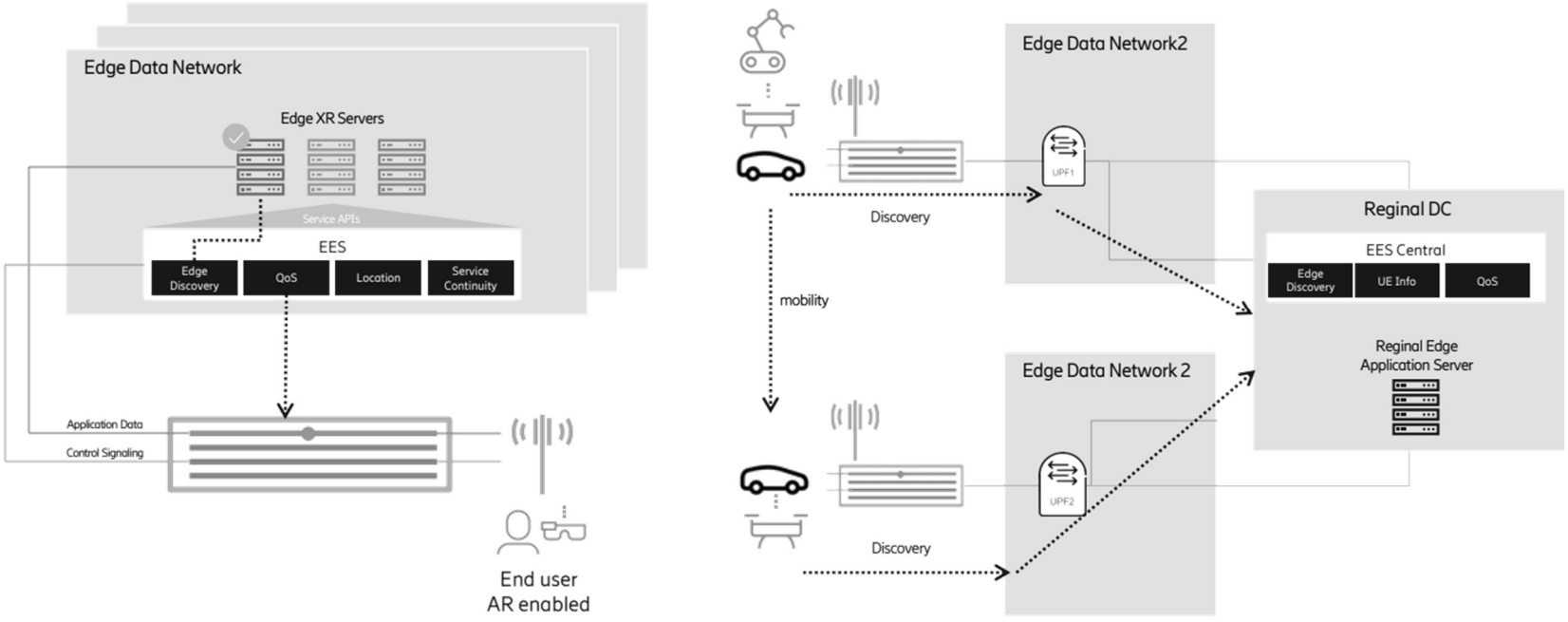
❖ Edge Exposure Server (EES)

- **Cloud Assisted XR**
- **Remote Control Ground/Aerial Vehicles**



Source: Ericsson-LG

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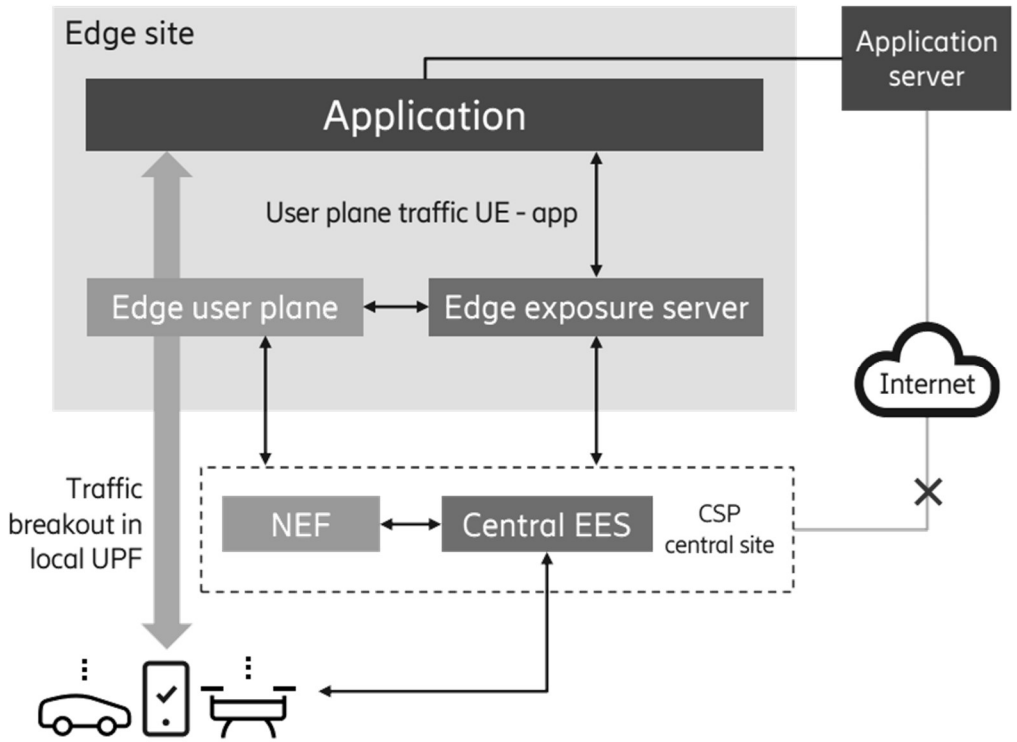
❖ Edge Exposure Server (EES)

- 엣지 애플리케이션을 위한 사용하기 쉬운 API



Source: Ericsson-LG

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❖ MEC는 저지연 서비스를 수익화 할 수 있는 기능을 제공

Public MEC

RAN Sites
RTT*
5/10 km
0.05/0.1 ms
Network Edge

County/City-wide Sites
RTT*
10/30 km
0.1/0.3 ms
Network Edge

Metro-wide Sites
RTT*
50/100 km
0.5/1.0 ms
Network Edge

State/Province-wide Sites
RTT*
250/500 km
2.5/5.0 ms
Network Edge

Private MEC

Industrial/ Enterprise Sites
RTT*
< 2.5 km
<0.025 ms
On-Premises

*RTT – Round Trip Time Propagation Delay – One-hop fiber link.
Multi-hop delay, compute time, and data storage/retrieval time to be added.
Geo-redundancy required for network reliability and to maintain low latency.

Source: Dell'Oro Group

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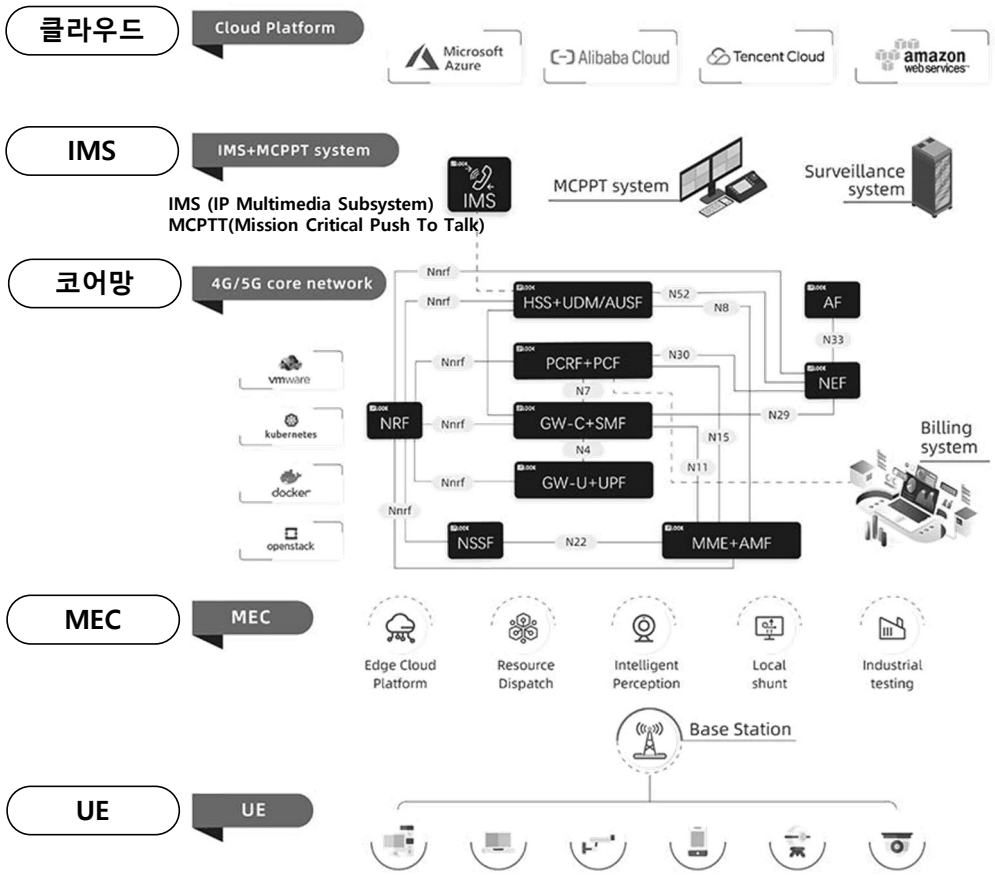
❖ **Deploy private 5G network on cloud(예)**

- **Cloud Platform**
- **IMS-MCPPT system**
- **4G/5G core network**
- **MEC** (Mobile Edge Computing)
- **UE** (User Equipment)



Source: https://www.iplook.com/info/deploy-private-5g-network-on-cloud-i00173i1.html

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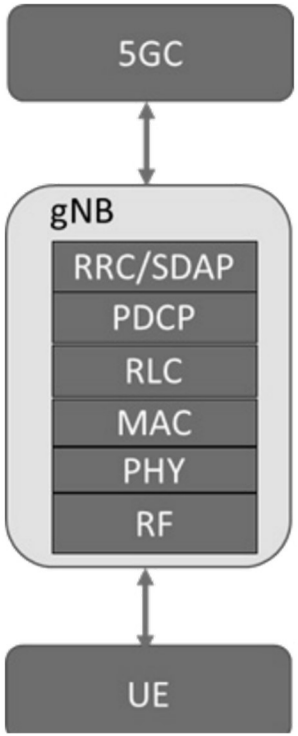
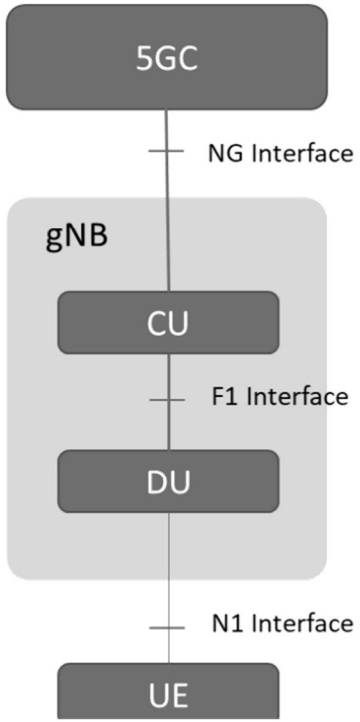
❖ **RAN 구조의 변화 (New C-RAN/Fronthaul)**





- **gNB (the NR logical node)**
- **Central Unit (CU)**
- **Distributed Unit (DU)**

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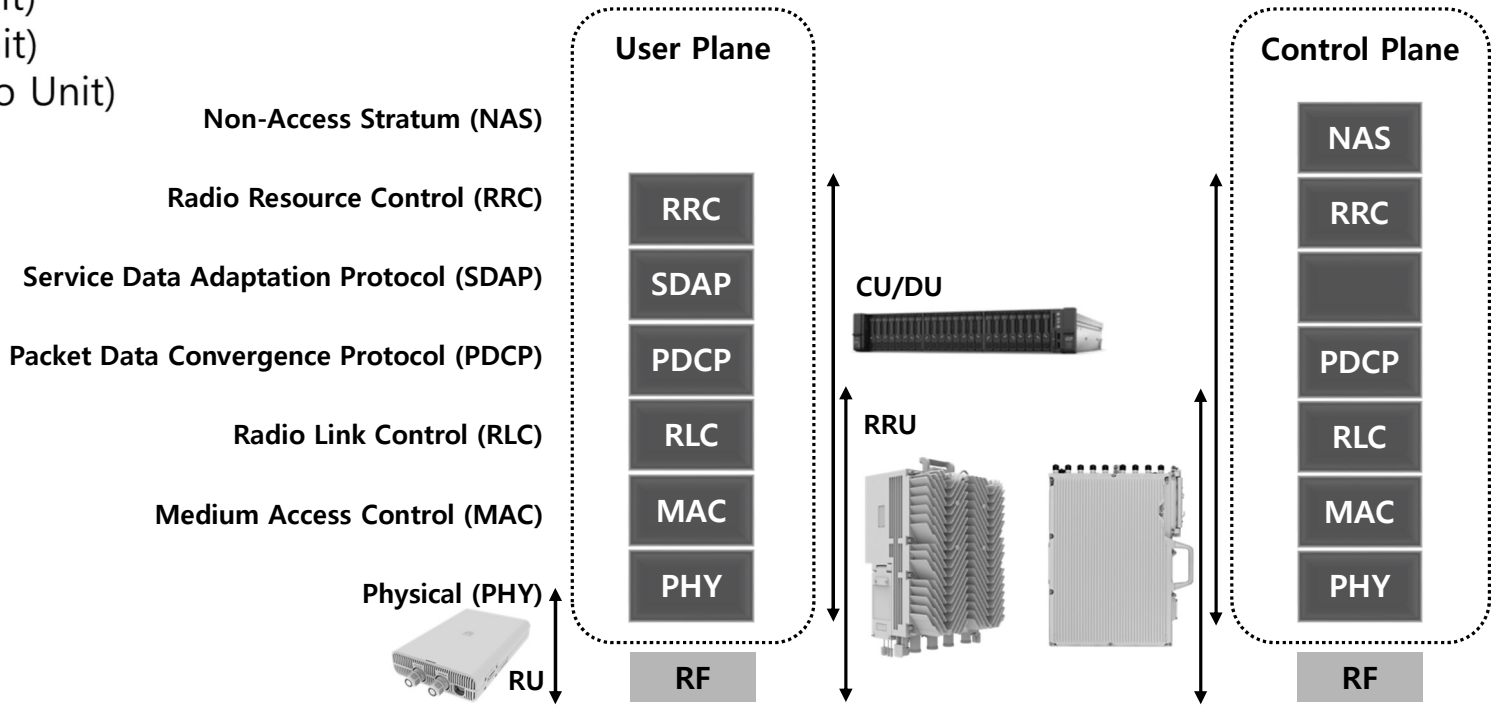
❖ Air Interface

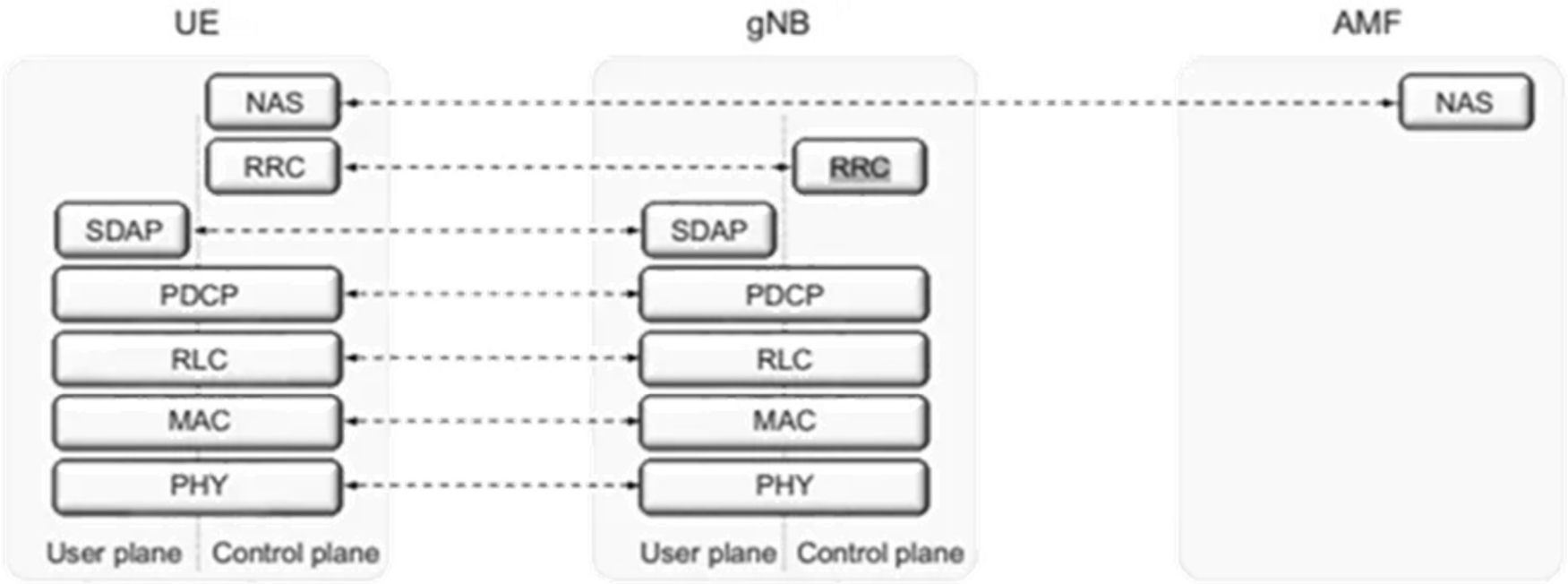
- **계층 구성** (Open Systems Interconnection Layer)
  - **CU** (Centralized Unit)
  - **DU** (Distributed Unit)
  - **RRU** (Remote Radio Unit)
  - **RU** (Radio Unit)



DAY 1: 5G 네트워크 개요

❖ **User-plane and Control-plane protocol stack in 5G NR**

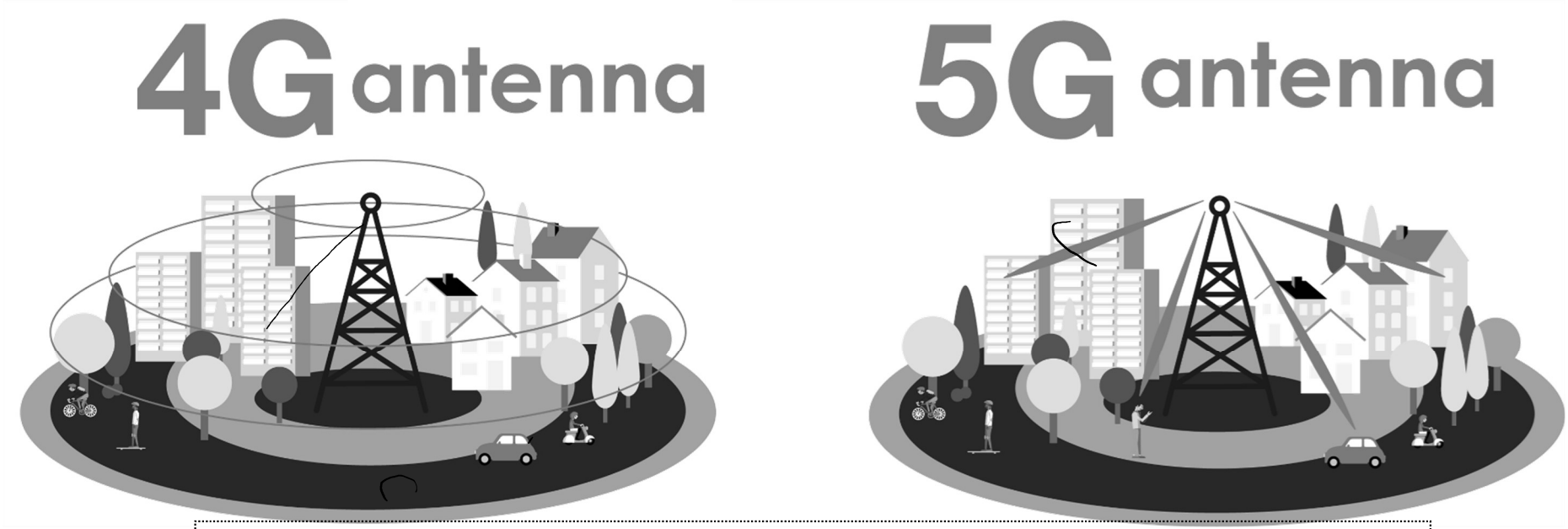
- **(Ref. 5G NR by E. Dahlman et al.)**



Source: https://syedshan85.medium.com/radio-resource-control-rrc-in-5g-nr-fa0782f83977

DAY 2: ENHANCED MOBILE BROADBAND

- ❖ 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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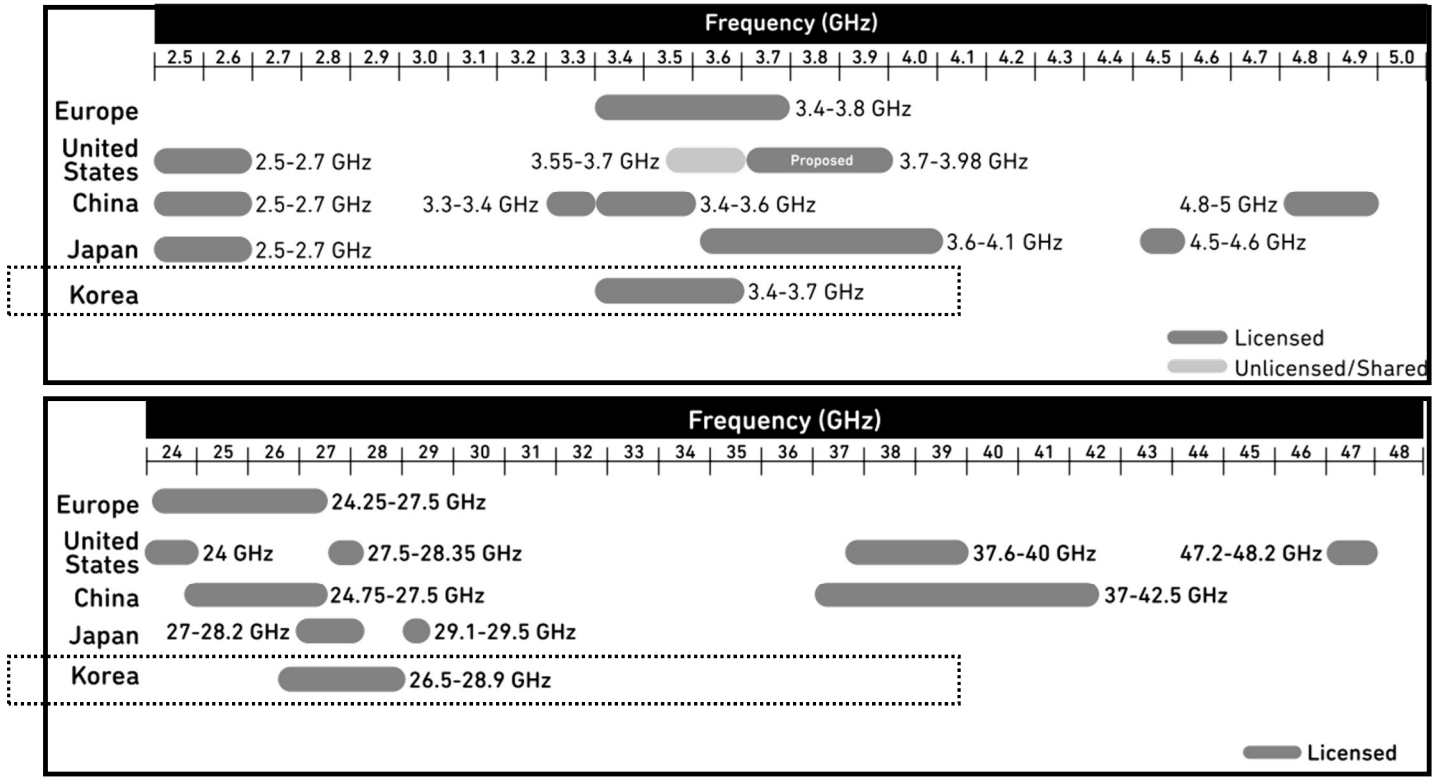
❖ **Global 5G band usage.**



Source: 5G RF, 2nd Qorvo Special Edition, by David Schnaufer, Tuan Nguyen, Ben Thomas, Alexis Mariani, Paul Cooper, Bror Peterson, Phil Warder

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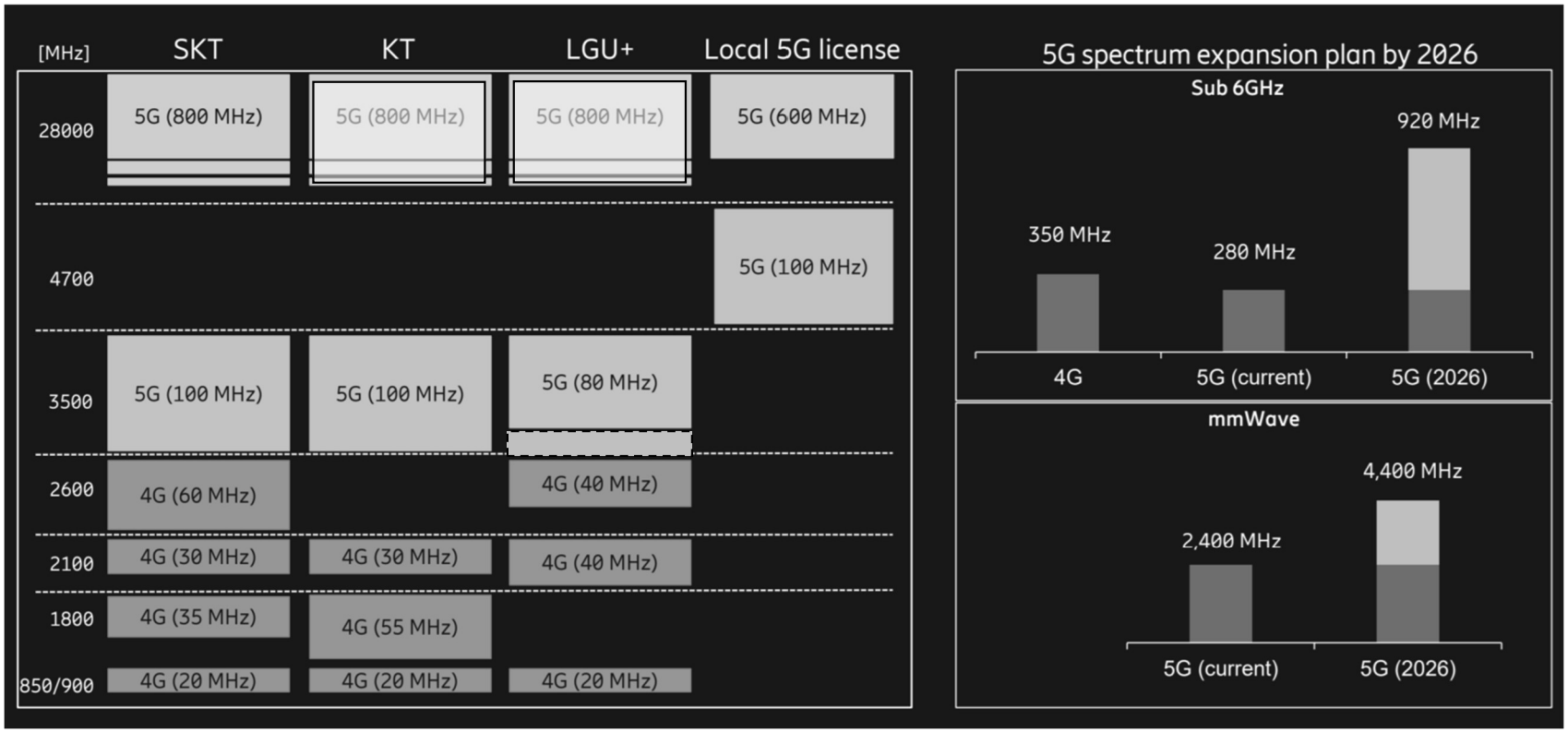
❖ Korea 5G & 4G Mobile spectrum asset



Source: https://blog.3g4g.co.uk/2022/03/realizing-zero-trust-architecture-for.html

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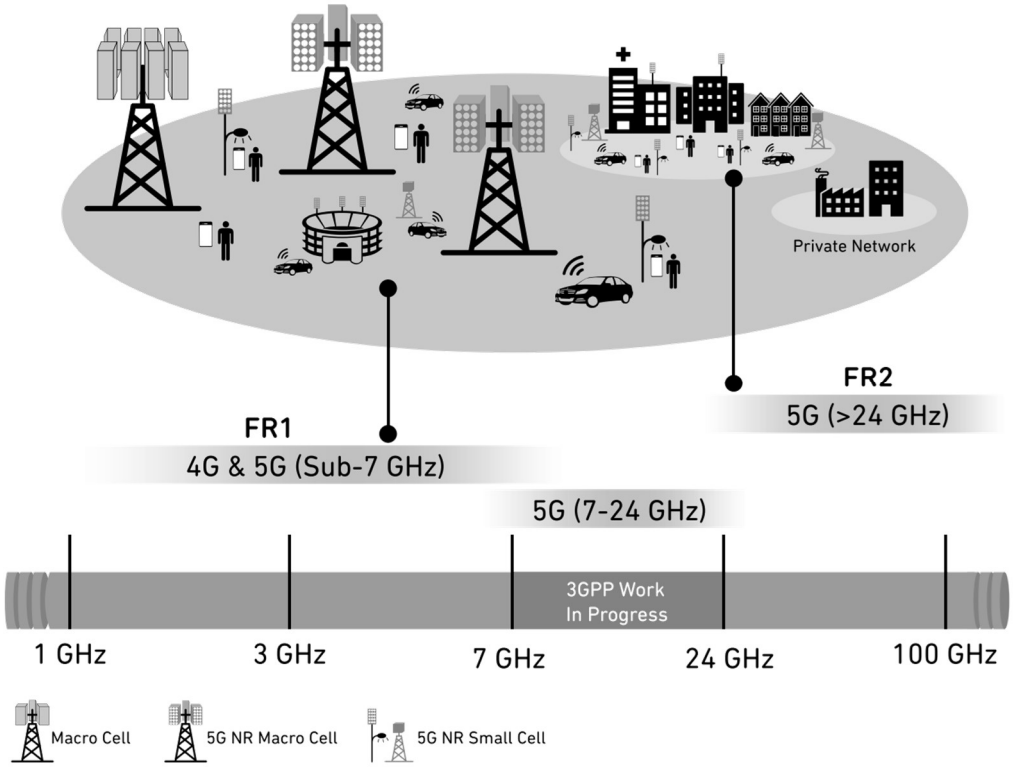
❖ **LTE-Advanced Pro and 5G NR ecosystem.**



Source: 5G RF, 2nd Qorvo Special Edition, by David Schnaufer, Tuan Nguyen, Ben Thomas, Alexis Mariani, Paul Cooper, Bror Peterson, Phil Warder

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❖ Frequency ranges FR1 and FR2.

*FR1

Band	Downlink/Uplink (GHz)
n77	3.30-4.20
n78	3.30-3.80
n79	4.40-5.00

**FR2

Band	Downlink/Uplink (GHz)
n257	26.50-29.50
n258	24.25-27.50
n259	39.50-43.50
n260	37.00-40.00
n261	27.50-28.35

Perameter	Frequency Range 1 (FR1)	Frequency Range 2 (FR2)
Also Known As	5G Sub-7 GHz	5G mmWave
Frequency Range	410-7,125 MHz (*includes n77, n78, n79) (reference: 3GPP: 38.101 v16.1.0)	24.25-52.6 GHz (**includes n257, n258, n259, n260, n261) (reference: 3GPP: 38.101 v16.1.0)
Transmission Bandwidths (CC)	5-100 MHz	50-400 MHz
Sub Carrier Spacing	15 kHz, 30 kHz, 60 kHz	60 kHz, 120 kHz, 240 kHz
Carrier Aggregation	Up to 16 carriers	Up to 16 carriers
Waveform & Modulation	CP-OFDM (UL/DL), DFT-s-OFDM (UL): QPSK, 16 QAM, 64 QAM, 256 QAM)	CP-OFDM (UL/DL), DFT-s-OFDM (UL): π/2-BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM
MIMO	Up to 8 layers in DL, up to 4 layers in UL	Up to 8 layers in DL, up to 4 layers in UL
Deployment Applications	Macro cells/many mobile users/ long-range	Small cells/less users/Increased content/short-range
Challenges	Spatial multiplexing - delivers multiple parallel streams of data in same resource block	Beam steering for each mobile user
Spectral Efficiency	High, because of spatial multiplexing	Low spectral efficiency - less users and higher pathloss
Channel Characterization	Rich multi-path propagation	Few propagation pathways
Number of Simultaneous Users	Tens of users, large coverage area	Few users, small coverage area

Source: User Equipment (UE) radio transmission and reception 3GPP TS 38.101-2

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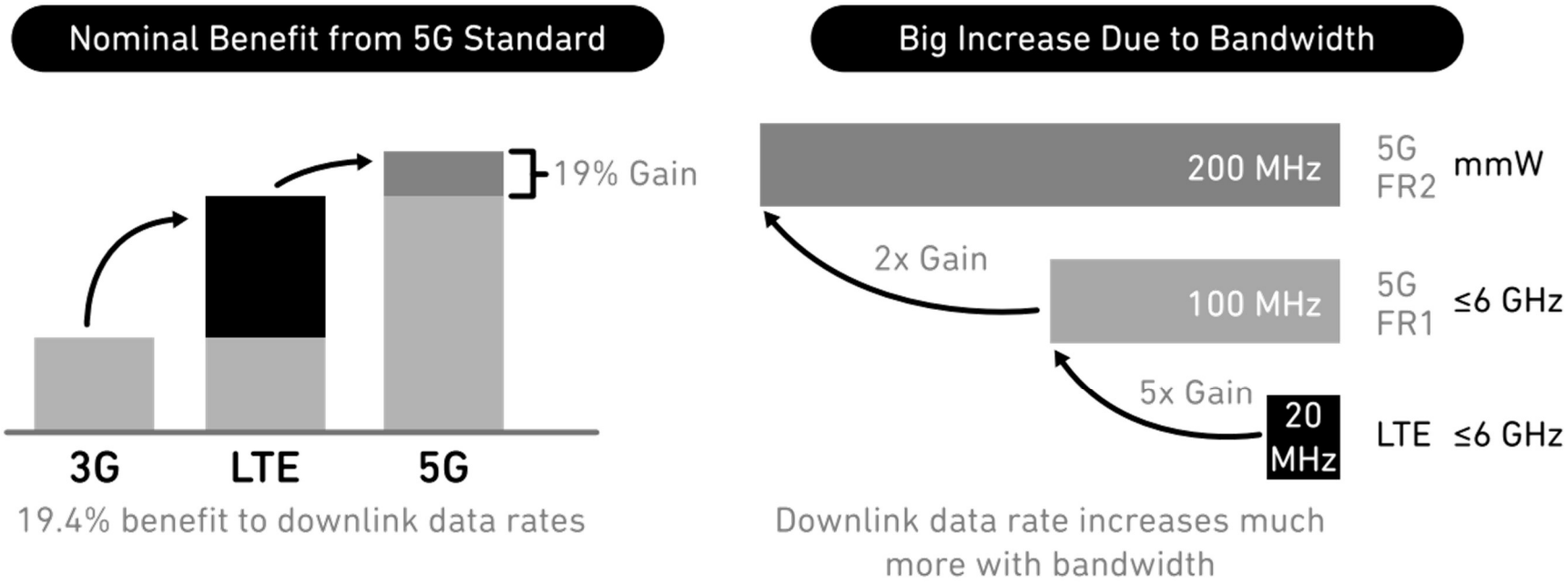
❖ **Comparing 4G LTE and 5G NR DL data improvements.**



Source: 5G RF, 2nd Qorvo Special Edition, by David Schnaufer, Tuan Nguyen, Ben Thomas, Alexis Mariani, Paul Cooper, Bror Peterson, Phil Warder

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❖ 5G 스펙트럼 사용으로 데이터 전송 속도 향상 및 비트당 전송 비용 절감

5G Frequency Ranges	Maximum RF Channel Bandwidth	Maximum CA Channel Bandwidth
FR1 410 MHZ – 7125 MHz	100 MHz	400 MHz
FR2-1 24250 MHz – 52600 MHz	400 MHz	800 MHZ
FR1 + FR2-1 – 410 MHz to 52600 MHz	n/a	1200 MHz
FR2-2 52600 MHz – 71000 MHz	400 MHz	1200 MHz
FR2-2 52600 MHz – 71000 MHz (optional)	2000 MHz	N/A

Source: User Equipment (UE) radio transmission and reception 3GPP TS 38.101-2

Carrier Aggregation (CA)

DAY 2: ENHANCED MOBILE BROADBAND

❖ **Base Station Types**

Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.01 to 0.1	1 to 30	Indoor
Pico cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/outdoor
Micro cell	1 to 10	0.2 to 2.0	100 to 2,000	Indoor/outdoor
Macro cell	10 to more than 50	8 to 30	More than 2,000	Outdoor

Source: 5G RF, 2nd Qorvo Special Edition, by David Schnaufer, Tuan Nguyen, Ben Thomas, Alexis Mariani, Paul Cooper, Bror Peterson, Phil Warder

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❖ Video Traffic 과 대역폭

- **Required data rates of 1080p and 720p video (~6.8 Mbps)**
- **Required data rate of UHD video (300 Mbps)**

Video type	Video resolution	Frame rate (FPS)	Encoding scheme	Required data rate
720p	1280 × 720	60	H.264	3.8 Mbit/s
1080p	1920 × 1080	40	H.264	4.5 Mbit/s
1080p	1920 × 1080	60	H.264	6.8 Mbit/s

Video type	Video resolution	Frame rate (frame per second, FPS)	Encoding scheme	Quality requirement	Required data rate
4 K UHD	3840 × 2160	50	HEVC	Medium quality	20–30 Mbit/s
4 K UHD	3840 × 2160	50	HEVC	High quality	~75 Mbit/s
4 K UHD	3840 × 2160	50	AVC	High quality	~150 Mbit/s
8 K UHD	7680 × 4320	50	HEVC	High quality	~300 Mbit/s

Springer

Source: 5G System Design, An End to End Perspective, Wan Lei • Anthony C. K. Soong, Liu Jianghua • Wu Yong • Brian Classon, Weimin Xiao • David Mazzarese, Zhao Yang • Tony Saboorian

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❖ Required data rate of VR (w/Round-trip delay)

VR level		Video resolution	Single-eye resolution	Frame rate (FPS)	Encoding scheme	Color depth	Required instantaneous data rate		Round-trip delay
Entry-level VR	Weak interaction	Full-view 8 K 2D/3D video (full-frame resolution 7680 × 3840)	1920 × 1920 [with view angle of 110°]	30	H.265	8	Field of view (FOV): 40 Mbps (2D) 63 Mbps (3D)	Full view: 75 Mbps (2D) 120 Mbps (3D)	30 ms (2D) 20 ms (3D)
	Strong interaction			90			120 Mbps (2D) 200 Mbps (3D)		10 ms
Advanced VR	Weak interaction	Full-view 12 K 3D video (full-frame resolution 11,520 × 5760)	3840 × 3840 [with view angle of 120°]	60	H.265	10	FOV: 340 Mbps	Full view: 630 Mbps	20 ms
	Strong interaction			120			1.4 Gbps		5 ms
Ultimate VR	Weak interaction	Full-view 24 K 3D video (full-frame resolution 23,040 × 11,520)	7680 × 7680 [with view angle of 120°]	120	H.266	12	FOV: 2.34 Gbps	Full view: 4.4 Gbps	10 ms
	Strong interaction			200			3.36 Gbps		5 ms

Springer

Source: 5G System Design, An End to End Perspective, Wan Lei • Anthony C. K. Soong, Liu Jianghua • Wu Yong • Brian Classon, Weimin Xiao • David Mazzarese, Zhao Yang • Tony Saboorian

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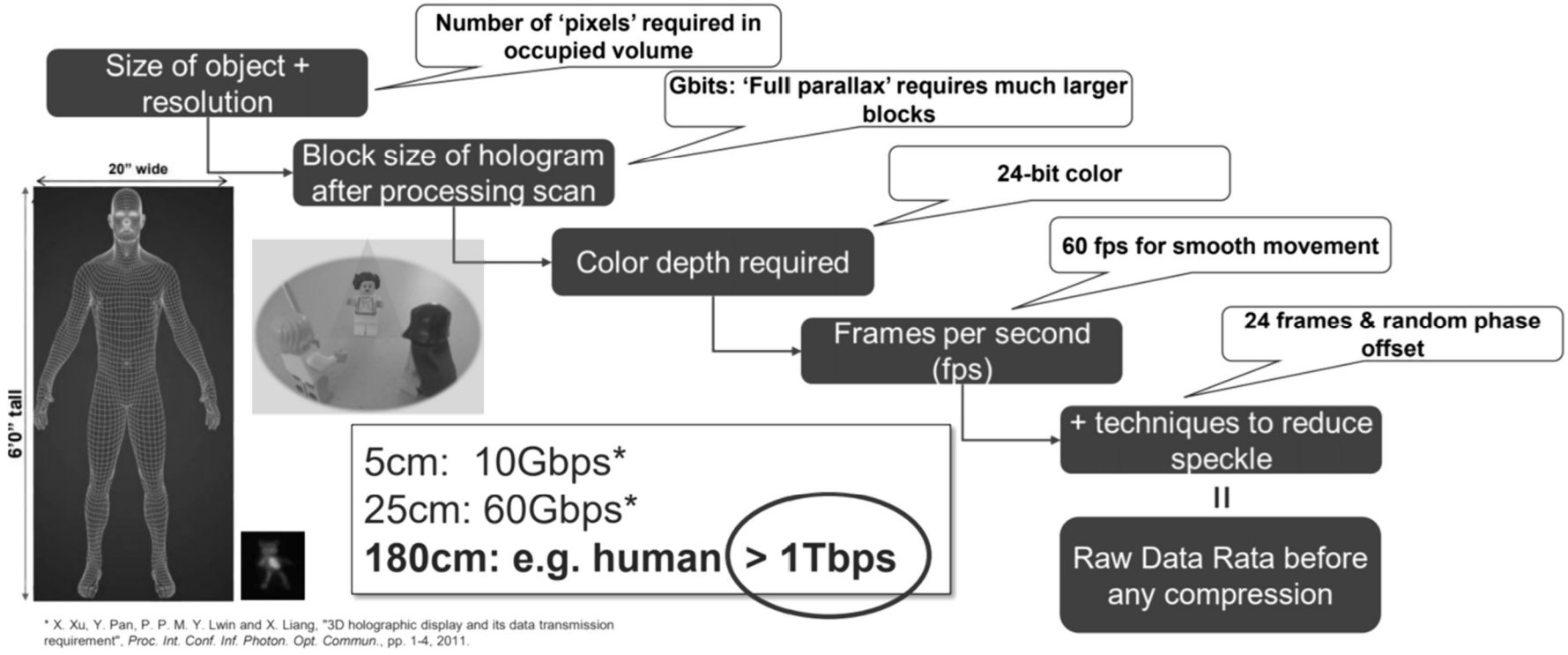
❖ **Holographic Telepresence ds:**



Source: Keysights

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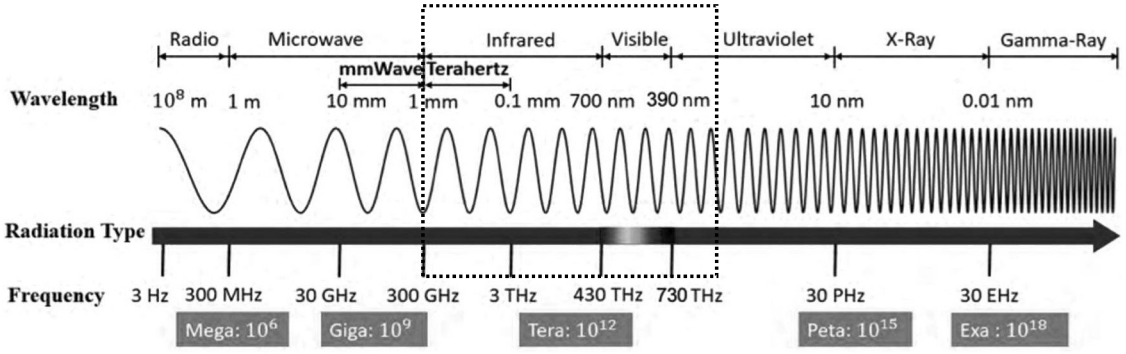
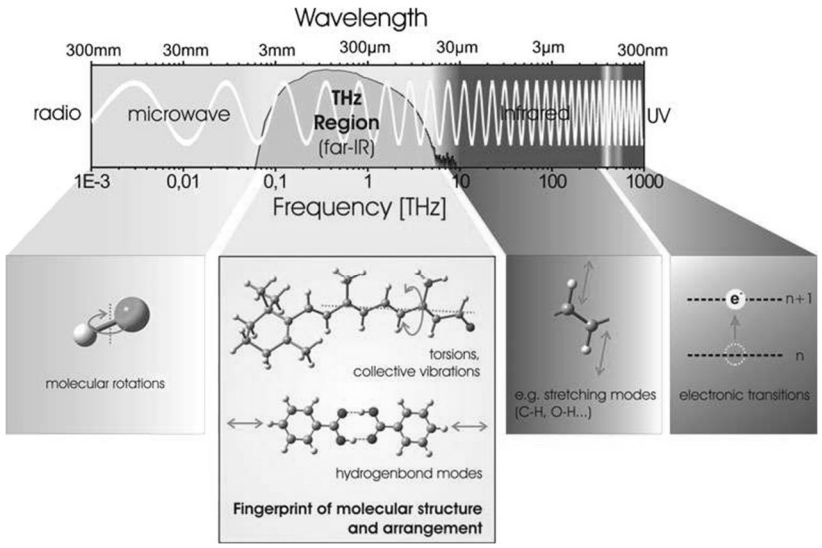
❖ THz



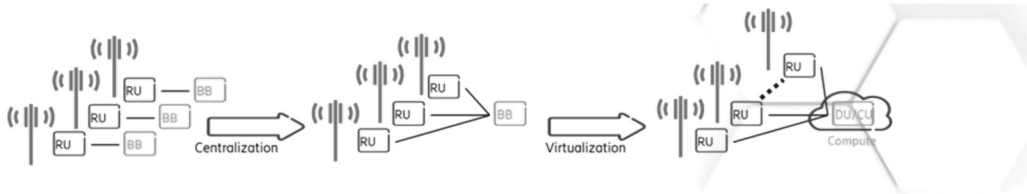


Source: User Equipment (UE) radio transmission and reception 3GPP TS 38.101-2

DAY 2: ENHANCED MOBILE BROADBAND

❖ Radio Access Network evolution

- Distributed RAN
- Centralized RAN
- Virtualized RAN



Enterprise	Distributed RAN	Centralized RAN	Virtualized RAN
Rationales	• Reduce transport cost • Smaller outage units at equipment failure • Reduced latency for end-user services • Data centers are limited by floor space and power supply	• Pooling of hardware resources (optimization) • Fewer nodes/sites leading to reduced CAPEX/OPEX • Competence consolidation • Energy efficiency	• Vendor agnostic comericial off-the-shelf (COTS) hardware to enable innovation across a range of a software ecosystem
Benefits	• Flexible backhaul • Use at most locations and scenarios	• Maximum radio coordination • Flexible baseband configuration and dimensioning/pooling	• Virtualization on General Purpose Processors (GPP i.e., x86)
Challenges	• Baseband dimensioning	• Strict delay requirements (i.e., fiber fronthaul) • Fronthaul/baseband single point of failure	• GPP inefficient for real time baseband processing (~1/10) • Diminishing returns on pooling

Source: Enterprise Evolution with 5G Adoption, A 5G America White Paper

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G NR 기술

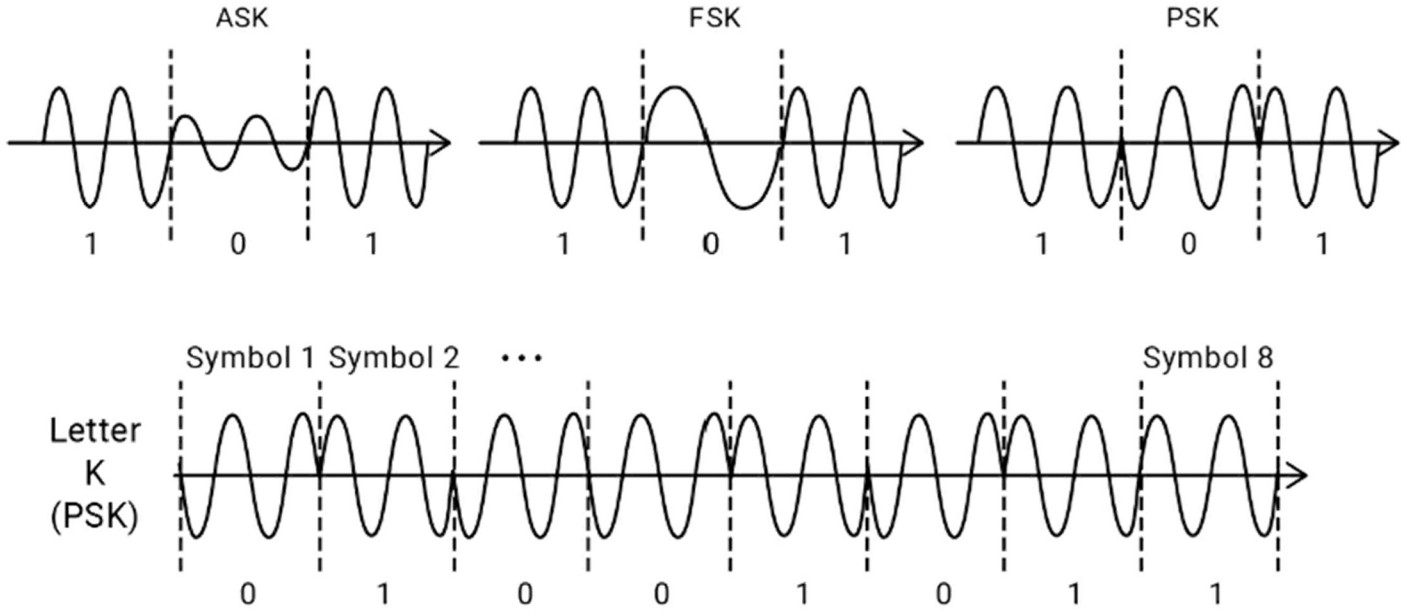
- **OFDM (Orthogonal frequency-division multiplexing)**
- **Self-contained slot based framework**
- **Channel Coding**
- **MU-MIMO**
- **mmWave**

Source: https://m.post.naver.com/viewer/postView.nhn?volumeNo=11764280&memberNo=20717909

❖ 단일 비트 진폭변조(ASK), 주파수변조(FSK) 및 위상변조(PSK).

• 아래 그림은 PSK 변조를 사용하여 모든 비트가 신호 변화(고유 심볼)에 문자 'K(ASCII 4B)'의 표현

- Amplitude shift keying (ASK),
- Frequency shift keying (FSK),
- Phase shift keying (PSK)



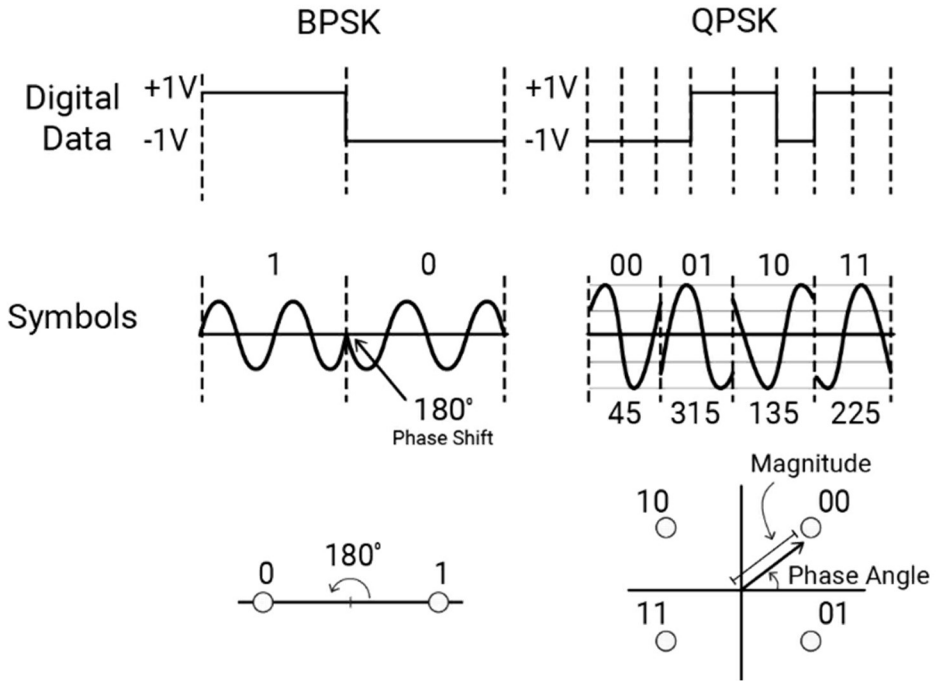
Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 84). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

❖ **BPSK 및 QPSK 변조의 바이너리 데이터 표현.**

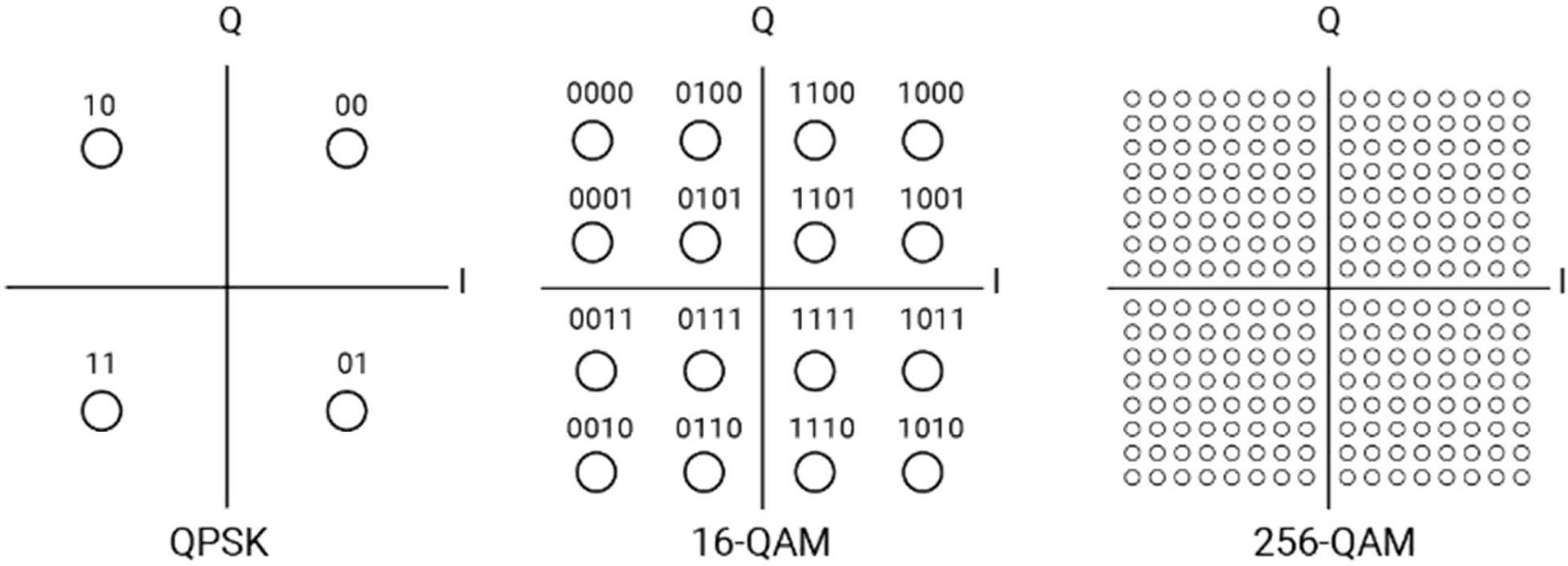
- **디지털 데이터 스트림은 별자리 다이어그램에서 점으로 표현할 수 있는 고유한 기호 집합으로 변환된다.**
- **BPSK는 심볼당 1비트 데이터를 인코딩하고 QPSK는 심볼당 2비트 데이터를 인코딩한다.**

- BPSK (Binary Phase Shift Keying)
- Quadrature Phase Shift Keying, QPSK)



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 127). Bitflip Media. Kindle Edition.

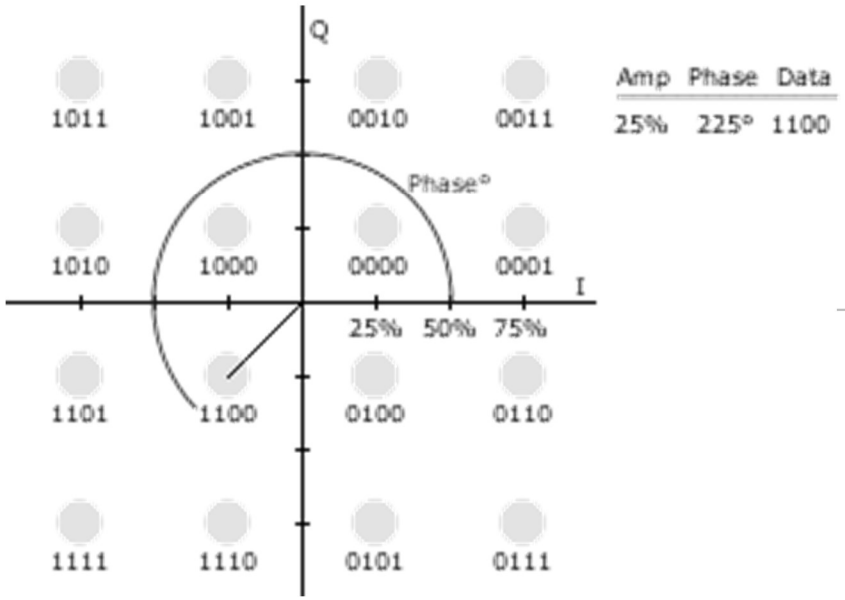
❖ **Constellation diagrams for QPSK, 16-QAM (with Gray coding), and 64-QAM.**



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 129). Bitflip Media. Kindle Edition. .

❖ QAM은 signal space(신호 공간) 개념과 복소평면을 사용 constellation 표현

16-QAM의 constellation (예)



64-QAM의 constellation (예)

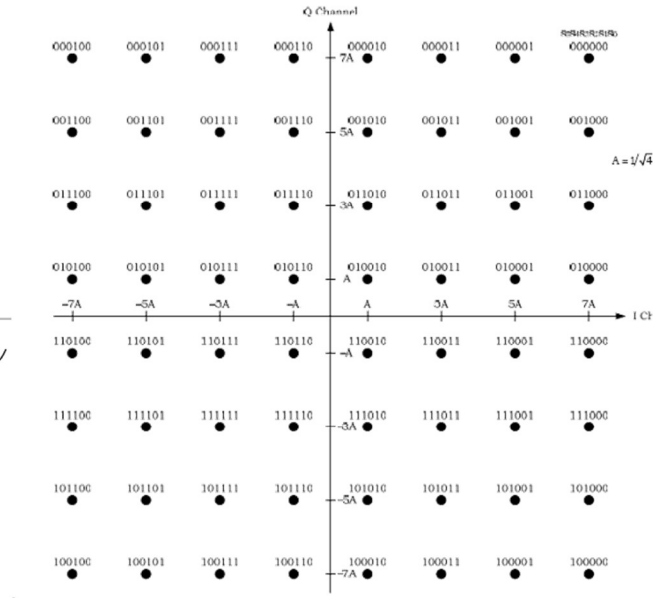
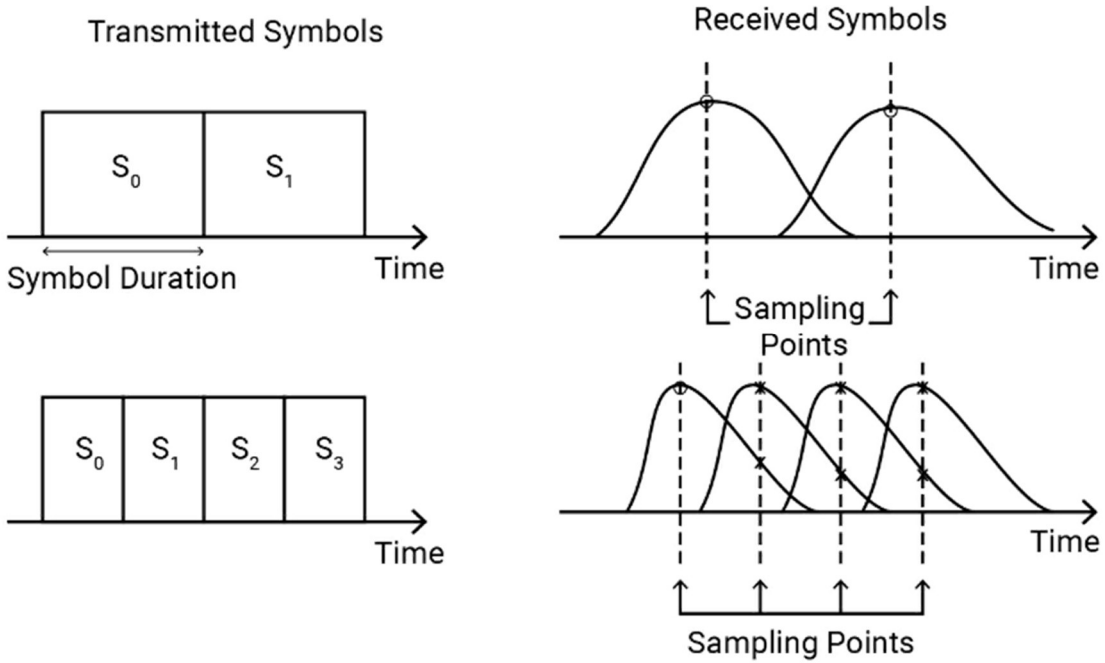


Figure 2.6.7.4-1. Signal Constellation for 64-QAM Modulation

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

❖ 심볼 간 간섭(Intersymbol interference, ISI) 및 심볼 지속 시간.

- 심볼 지속 시간이 길수록 ISI에 대해 더 견고하지만 처리량은 낮아진다. 일반적으로 심볼 지속 시간에 비해 최대 지연 스프레드가 길면 ISI가 커진다. 그러나 심볼 지속 시간이 지연 확산에 비해 길면 후속 심볼은 대부분 간섭 없이 수신된다.

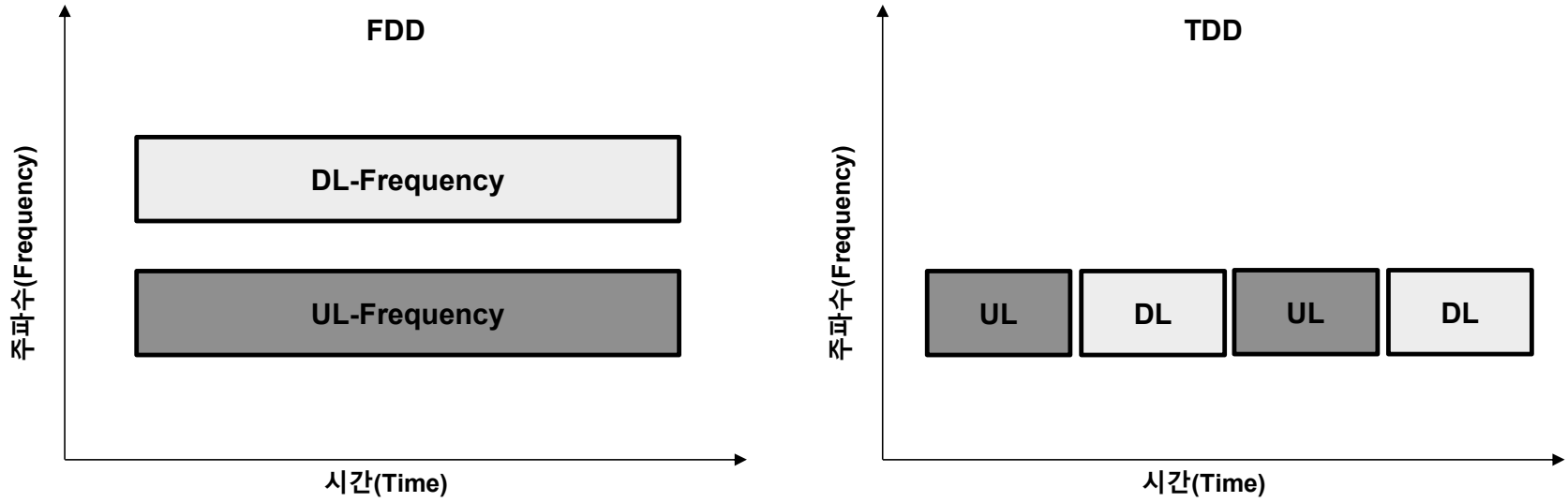


Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 139). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

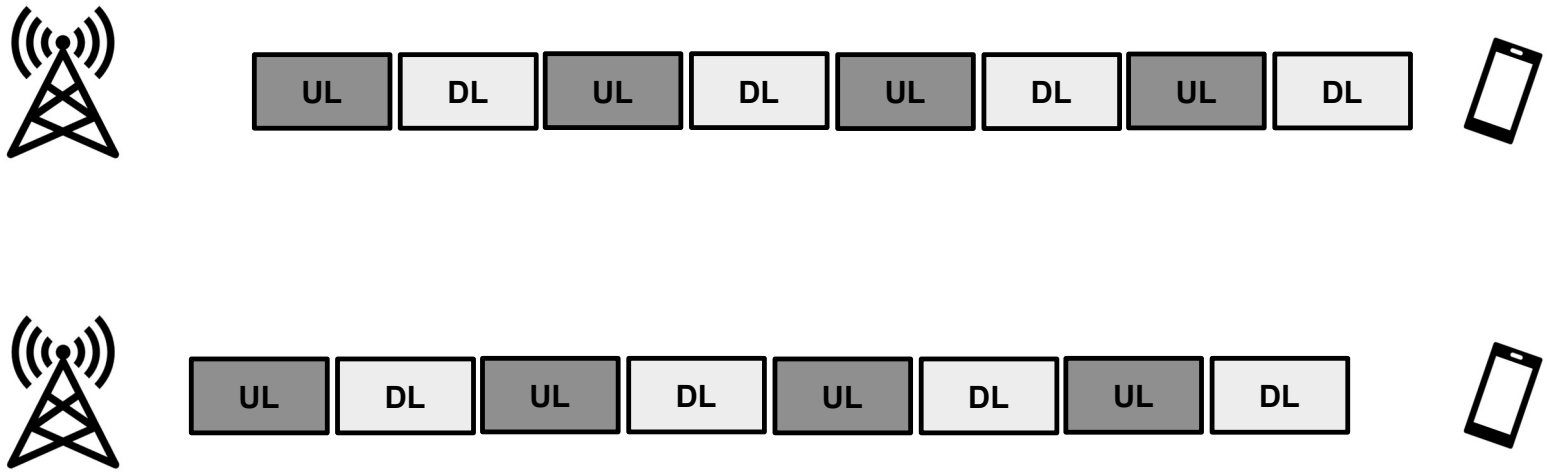
❖ FDD vs. TDD

- Frequency Division Duplex (FDD)
- Time Division Duplex (TDD)



DAY 2: ENHANCED MOBILE BROADBAND

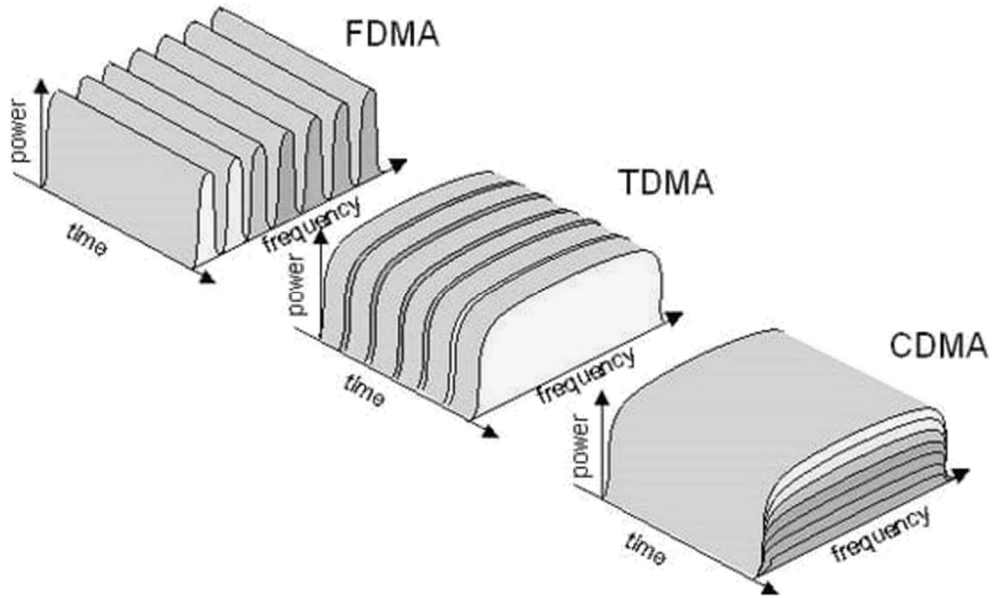
❖ TDD를 위한 동기화 고려



DAY 2: ENHANCED MOBILE BROADBAND

❖ 무선(Radio): 스펙트럼의 물리적 가용성을 향상시키는 방법으로 발전

- 주파수 분할: Frequency Division Multiple Access (FDMA)
- 시간 분할: Time Division Multiple Access (TDMA)
- 코드 분할: Code Division Multiple Access (CDMA)

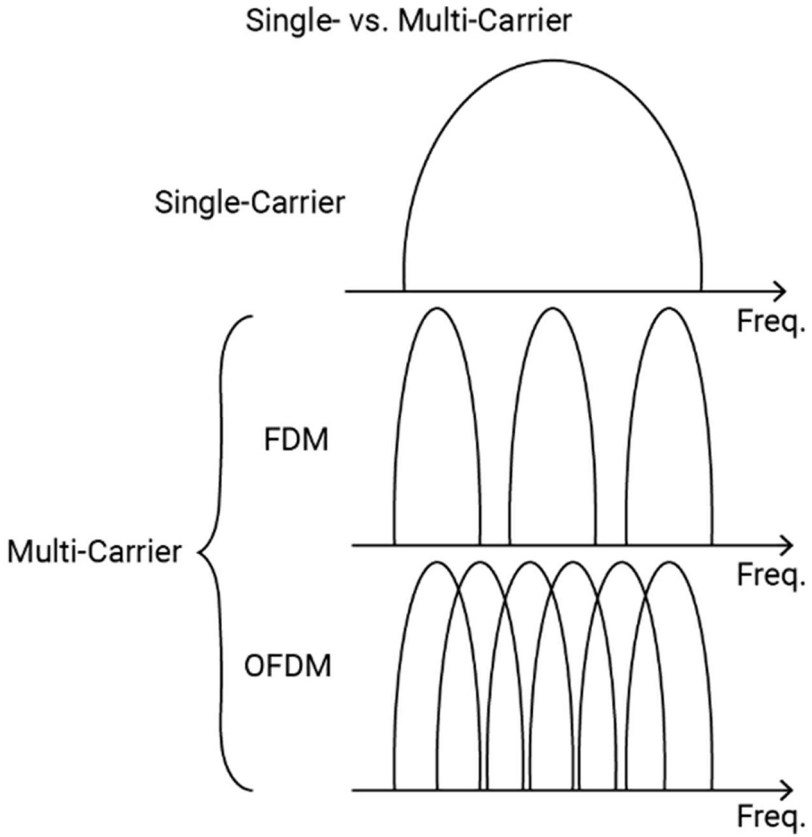


Source: https://networkencyclopedia.com/code-division-multiple-access-cdma/

DAY 2: ENHANCED MOBILE BROADBAND

❖ 단일 반송파 대 다중 반송파 시스템.

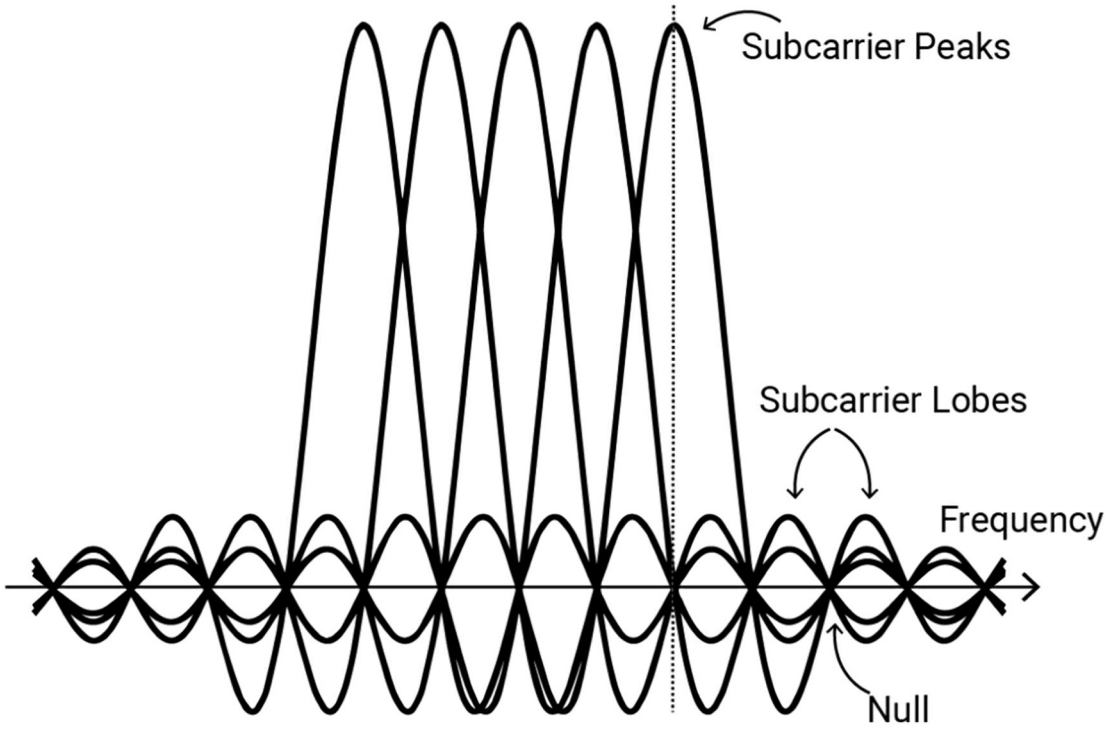
- OFDM은 기존 FDM보다 서브 캐리어를 더 조밀하게 패킹 할 수 있다.



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 143). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

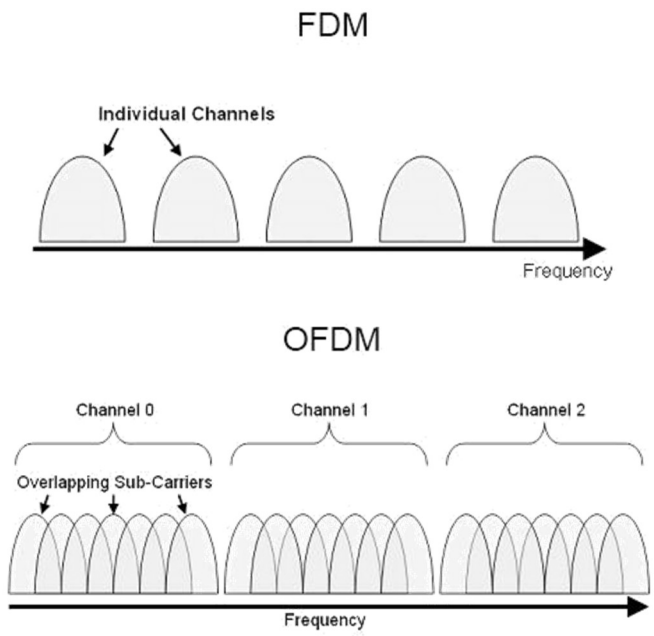
❖ **OFDM subcarriers formed via multiple orthogonal sinc functions.**

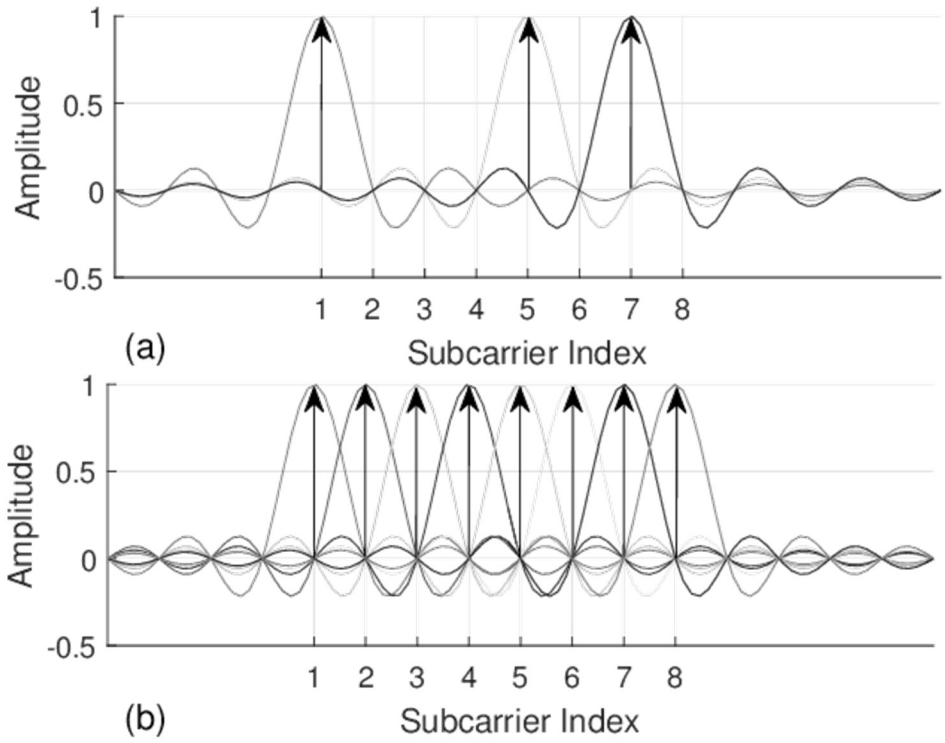


Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 145). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

- ❖ Waveforms and Mixed-Numerology
- ❖ OFDM 신호의 스펙트럼

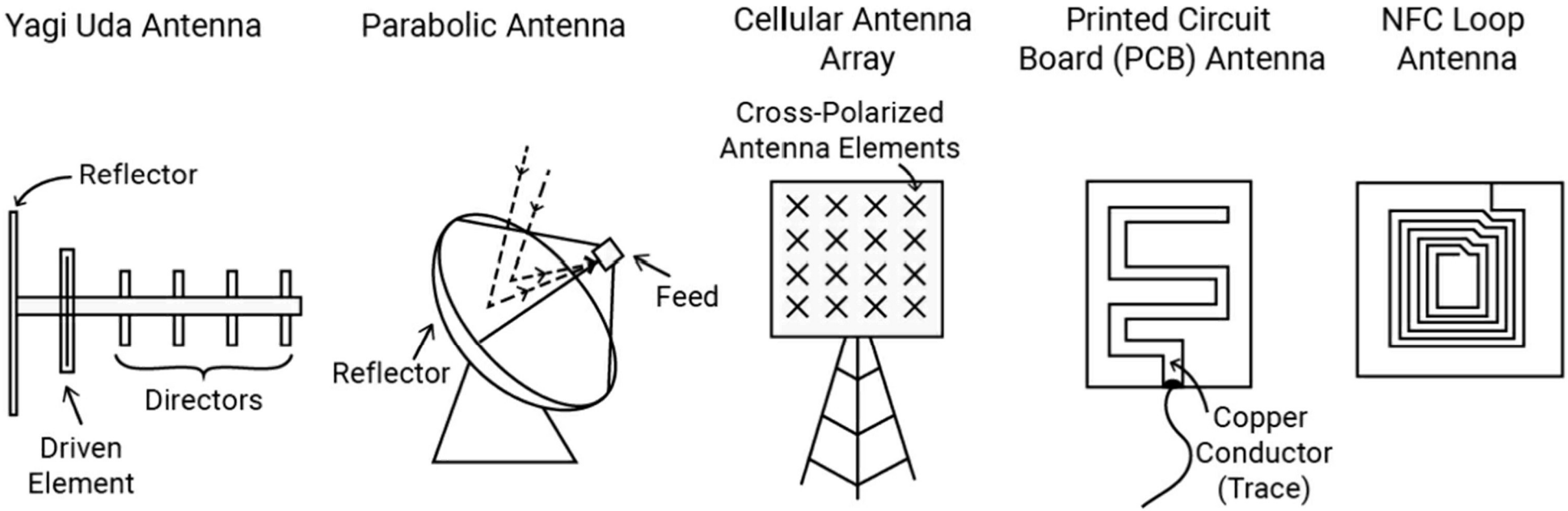




DAY 2: ENHANCED MOBILE BROADBAND

❖ **Types of antennas:**

- **야기(Yagi), 포물선형(parabolic), 교차 편파 소자가 있는 32소자 셀룰러 안테나 어레이(셀룰러 기지국 내), 인쇄 회로 기판(PCB) 표면에 그려진 2D 구조 안테나 및 근거리 통신 루프 안테나**



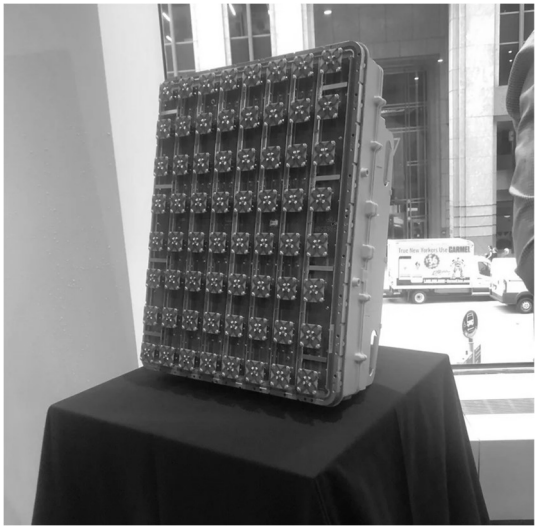
Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 170). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

❖ Massive MIMO (예)

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

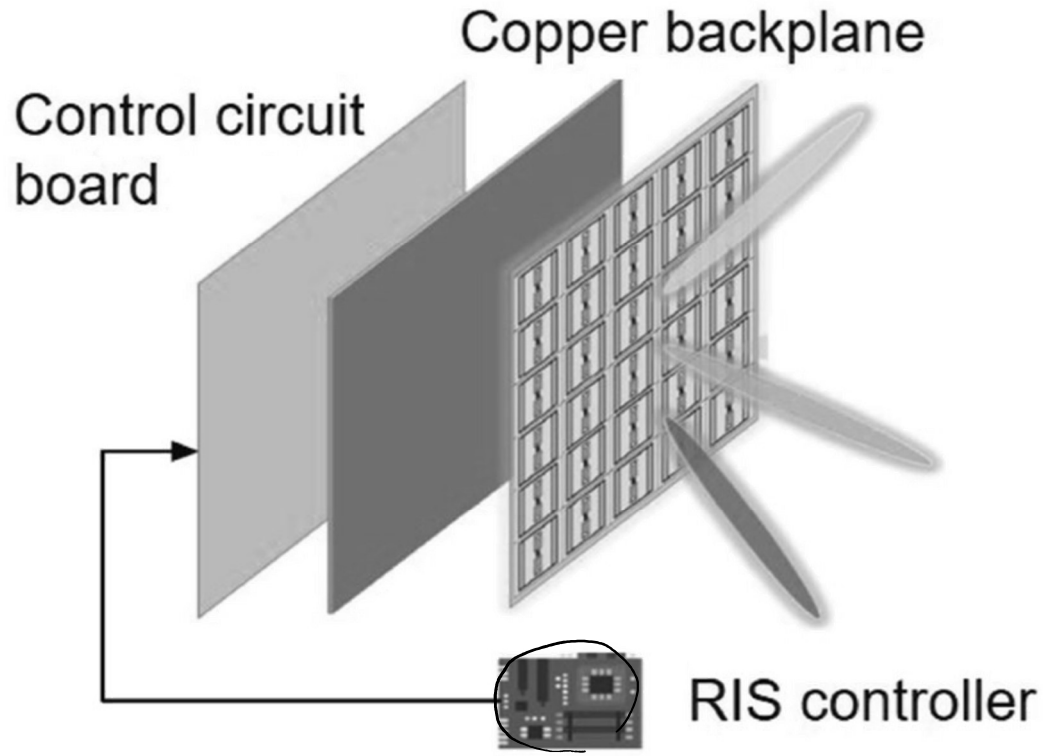
Aurora CMM.100.A 5-6GHz C-Band Massive MIMO Phased Array



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

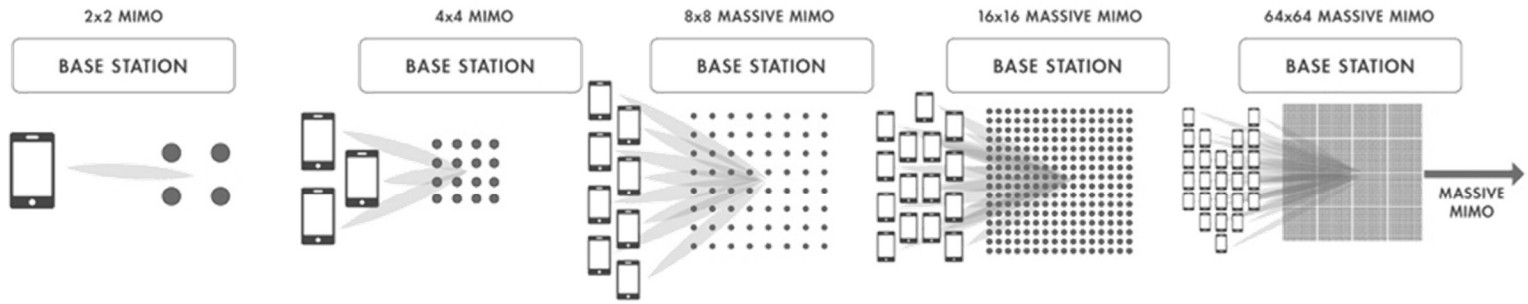
Source: https://medium.com/5g-nr/massive-mimo-75f775ead2e9
Source: https://www.fiercewireless.com/tech/t-mobile-exec-says-massive-mimo-can-be-used-tdd-and-fdd-bands

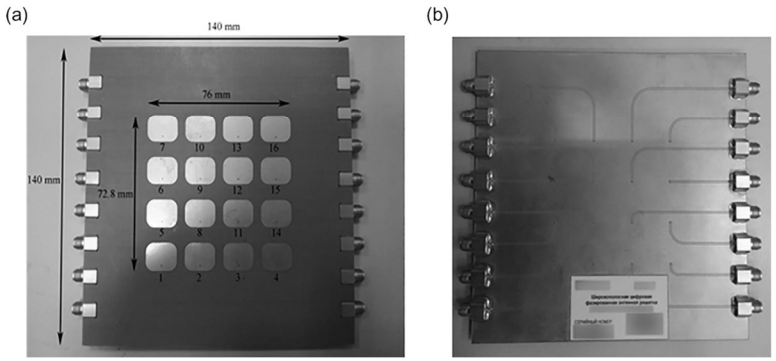
❖ O-RAN의 RIC(RAN Intelligent Controller) 제어



DAY 2: ENHANCED MOBILE BROADBAND

- ❖ 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/

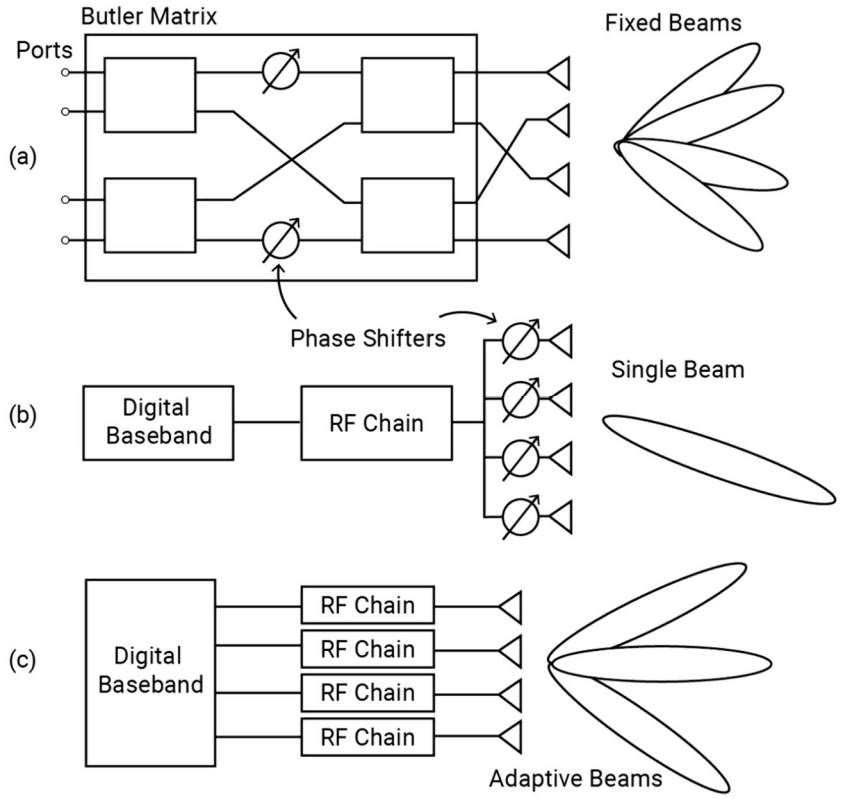
DAY 2: ENHANCED MOBILE BROADBAND

❖ Types of MIMO

a. **버틀러 매트릭스를 통한 패시브 빔포밍**
   - Passive beamforming via a Butler matrix

b. **위상 어레이를 통한 단일 빔 아날로그 빔포밍**
   - single-beam analog beamforming via phased arrays

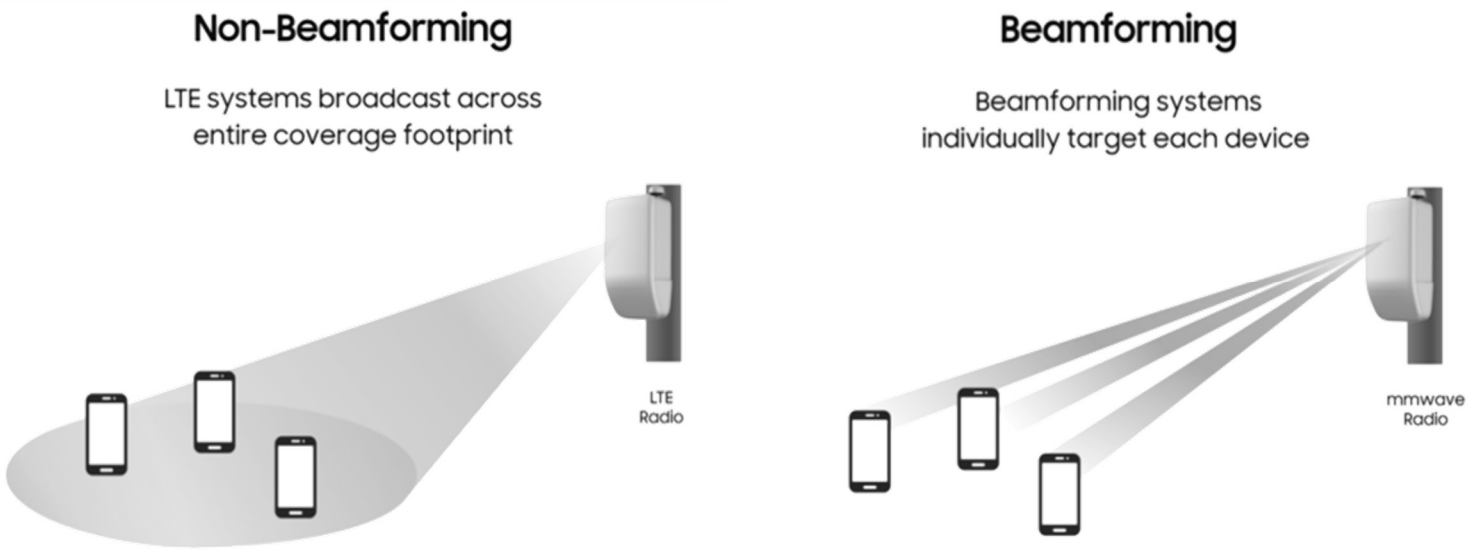
c. **적응형 디지털 빔포밍.**
   - adaptive digital beamforming.



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 194). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

- ❖ 기존 안테나와 Beamforming 비교
- ❖ 빔포밍은 동일 주파수를 재사용하며 지향성으로 고속도 지원



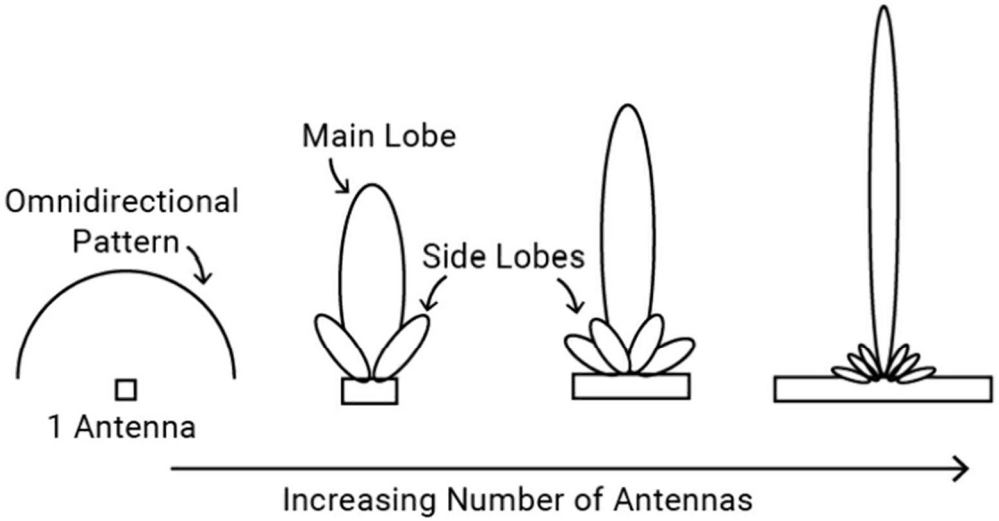
(출처: Case study: Orange Romania, Samsung)

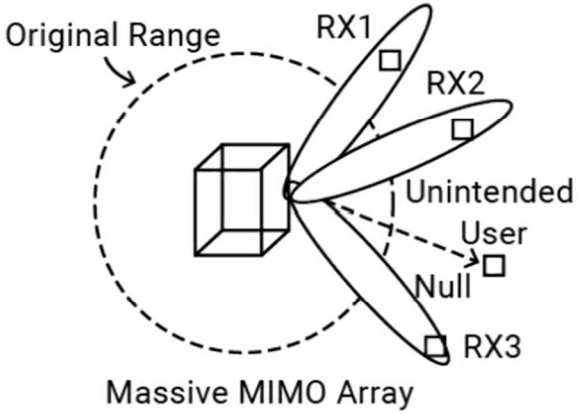
빔포밍(Beamforming): 빔 스티어링은 모든 방사 요소에서 입력 신호의 위상을 변경함으로써 달성하며, 위상변조를 통해 신호가 특정 수신기를 대상으로 할 수 있음

DAY 2: ENHANCED MOBILE BROADBAND

❖ **Beam pattern for different numbers of antennas in an array.**

- 안테나 수를 늘리면 에너지가 한 방향으로 더 집중되지만 작은 사이드 로브의 수는 증가
- 마지막 그림은 세 명의 동시 사용자에게 서비스를 제공하고 의도하지 않은 사용자 한 명에 대해 널링(에너지 억제)을 수행하는 대규모 MIMO 어레이 매시브 MIMO는 MU-MIMO의 확장된 버전으로 생각할 수 있음 (빔포밍이 없는 시스템의 원래 범위도 보여줌)





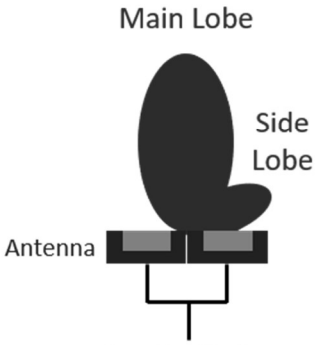
Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 206). Bitflip Media. Kindle Edition.

DAY 2: ENHANCED MOBILE BROADBAND

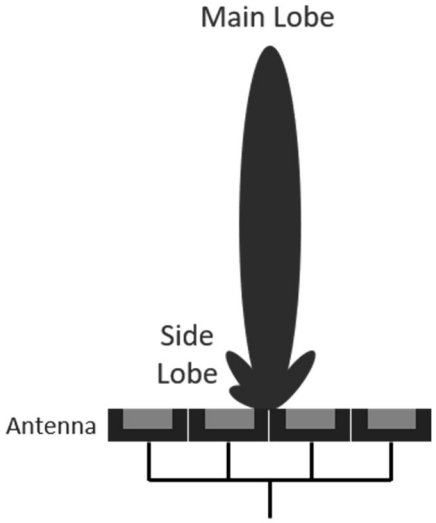
❖ 빔포밍 (What is 5G beamforming?)

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

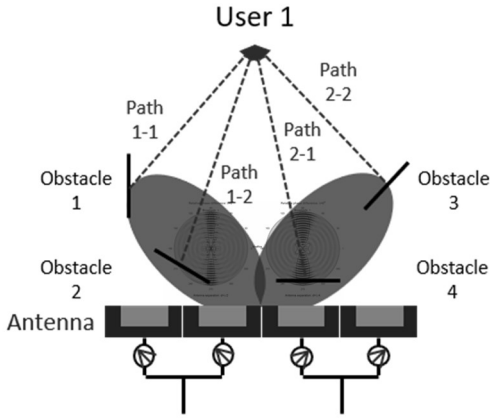
One Radiating Element



Two Radiating Elements



Four Radiating Elements

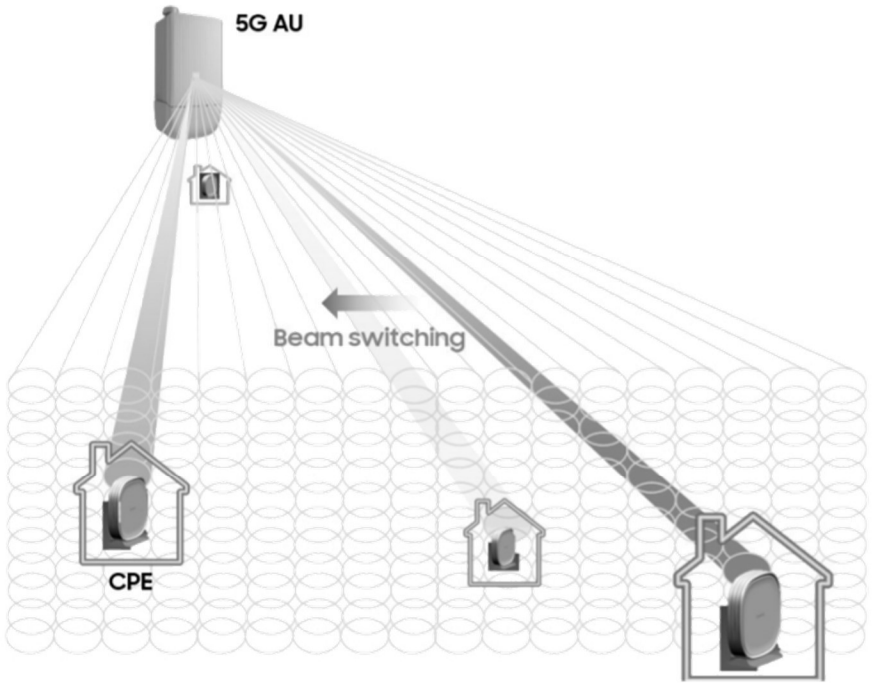


Four Radiating Elements at a common frequency with 45° the other with -45° phase shift supporting MIMO for increasing SNR and channel capacity

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

DAY 2: ENHANCED MOBILE BROADBAND

❖ **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

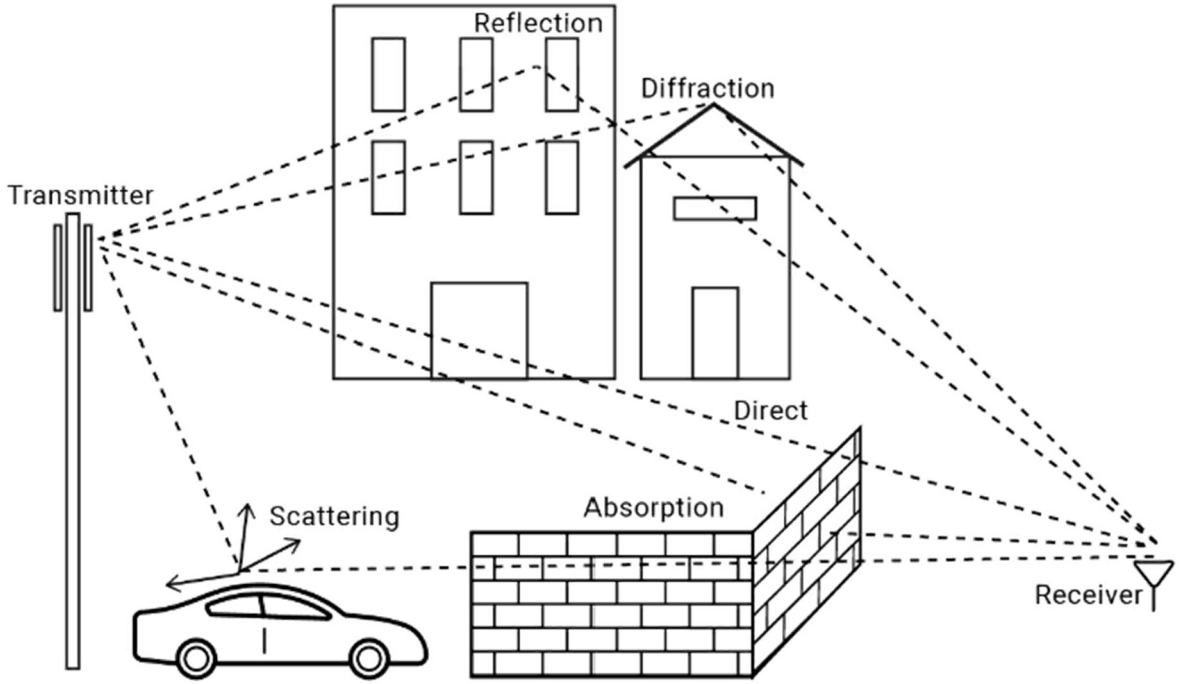


Source: Case study: Orange Romania, Samsung

DAY 2: ENHANCED MOBILE BROADBAND

❖ **신호 전파 효과** (Signal propagation effects).

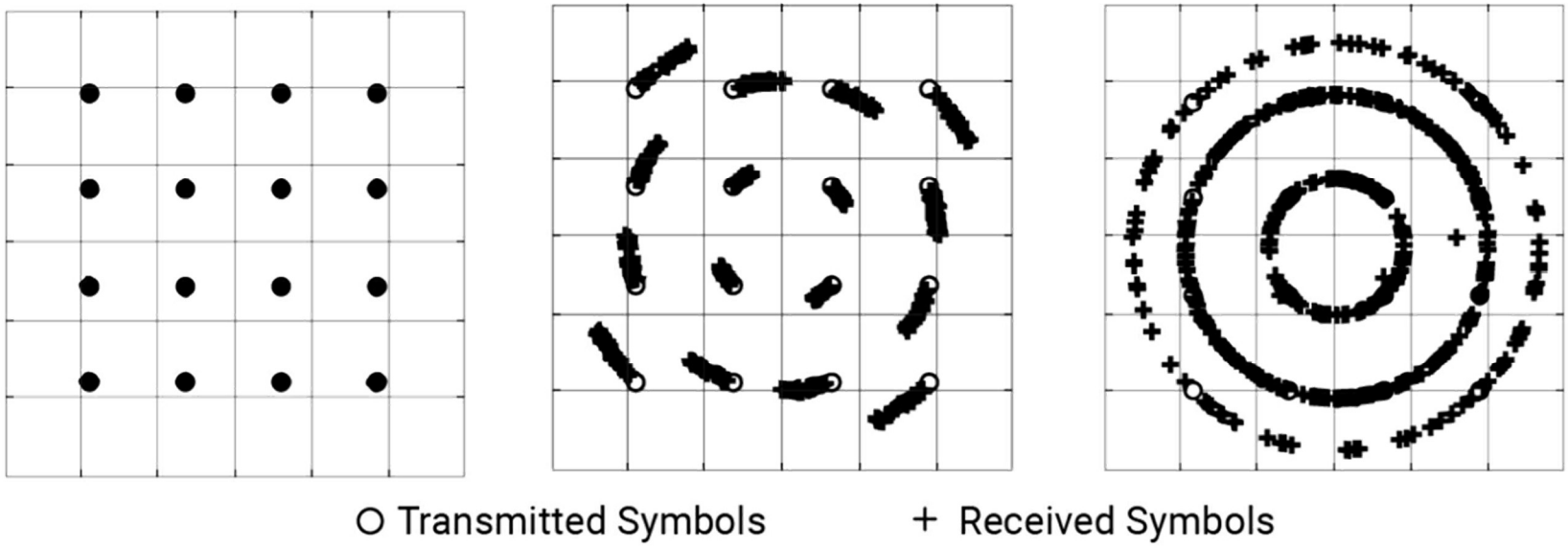
- **서로 다른 경로로 인해 동일한 신호의 여러 복사본이 수신기에 도착하게 된다.**



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 44). Bitflip Media. Kindle Edition.

❖ 반송파 주파수 오프셋(CFO) 보정 유무에 관계없이 수신된 constellation (16-QAM)

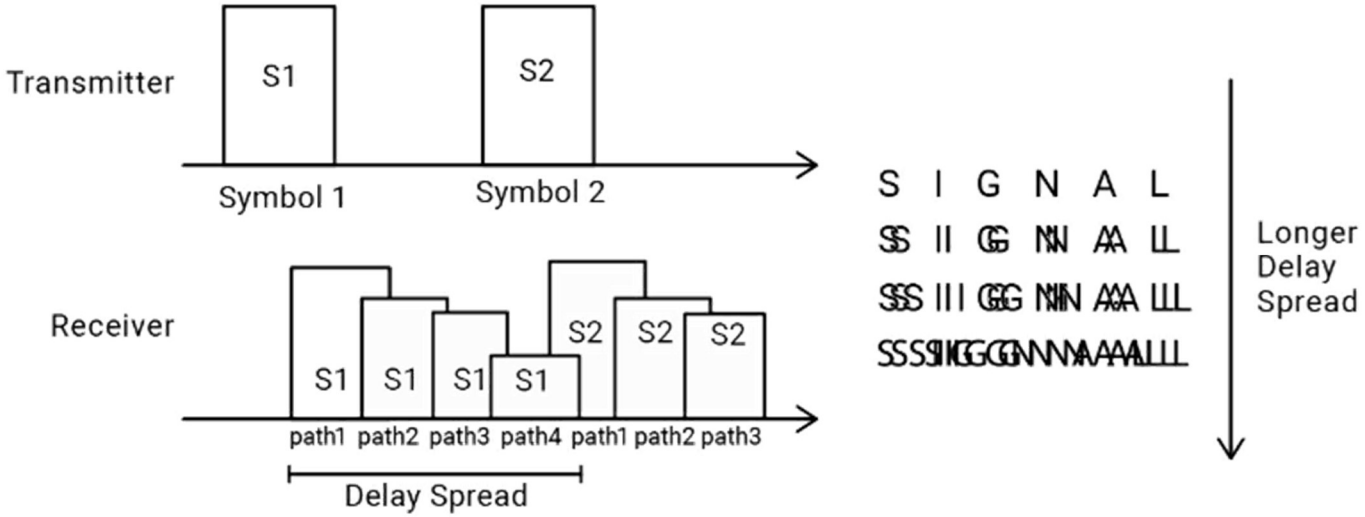
- (Left) Perfect constellation after CFO correction.
- (Middle) Relatively low CFO error with no correction.
- (Right) High CFO error with no correction.



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (p. 183). Bitflip Media. Kindle Edition.

❖ 기호 간 간섭 (Intersymbol interference, ISI):

- 지연 확산이 전송된 심볼 사이의 간격보다 길면 심볼 "번짐"이 관찰된다. 예를 들어 'SIGNAL'이라는 단어를 전달하면서 각 문자를 별도의 심볼로 전송한다고 가정해 보면, 지연 스프레드가 짧으면 각 글자가 '흐릿하게' 보일 수 있지만 여전히 메시지를 이해할 수 있다. 그러나 지연 시간이 너무 길어 글자가 겹치면 더 이상 메시지를 이해할 수 없게 된다.



Source: Bejarano, Oscar. Wireless: A Total Beginner's Guide to Modern Wireless Communication Technologies (pp. 49-50). Bitflip Media. Kindle Edition.

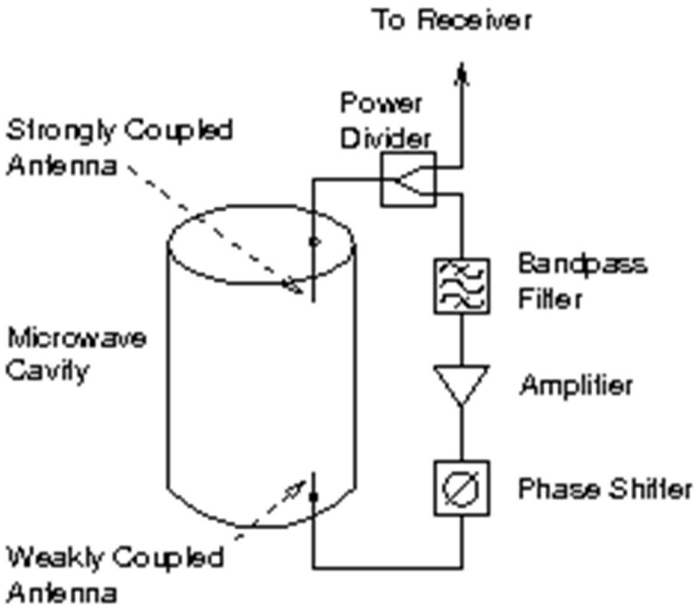
DAY 2: ENHANCED MOBILE BROADBAND

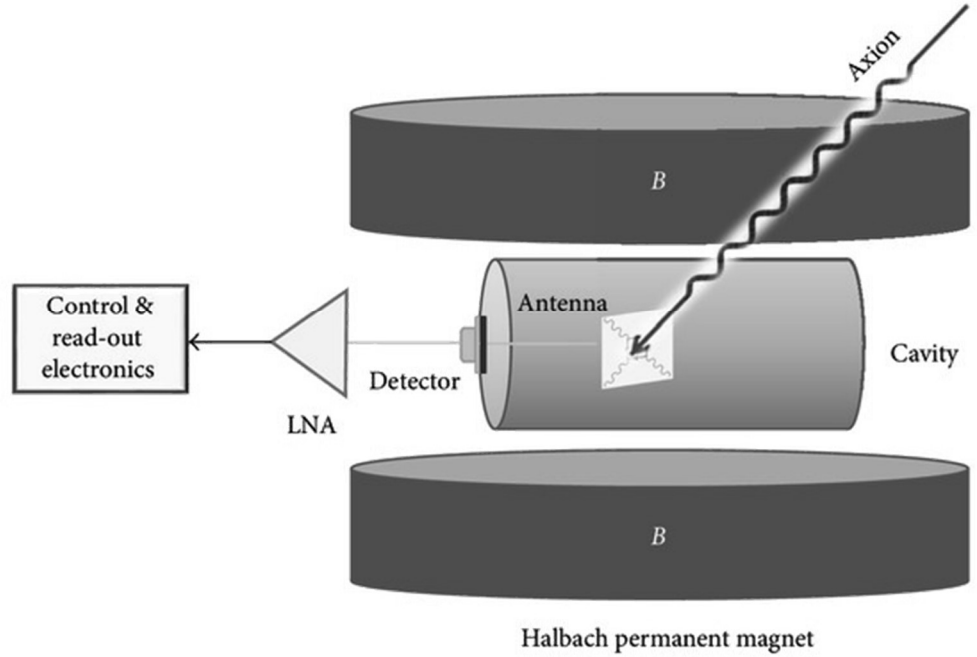
❖ **Wi-Fi Routers Used to Detect Human Locations, Poses Within a Room**

Source: https://www.tomshardware.com/news/wi-fi-routers-used-to-detect-human-locations-poses-within-a-room

DAY 2: ENHANCED MOBILE BROADBAND

❖ Axion Detector



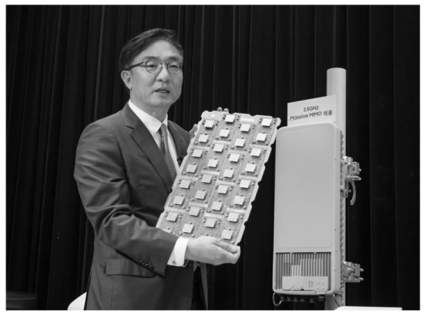


Source: https://ui.adsabs.harvard.edu/abs/2014arXiv1403.6720R/abstract
Source: https://www.hindawi.com/journals/ahep/2017/6432354/

DAY 2: ENHANCED MOBILE BROADBAND

❖ 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

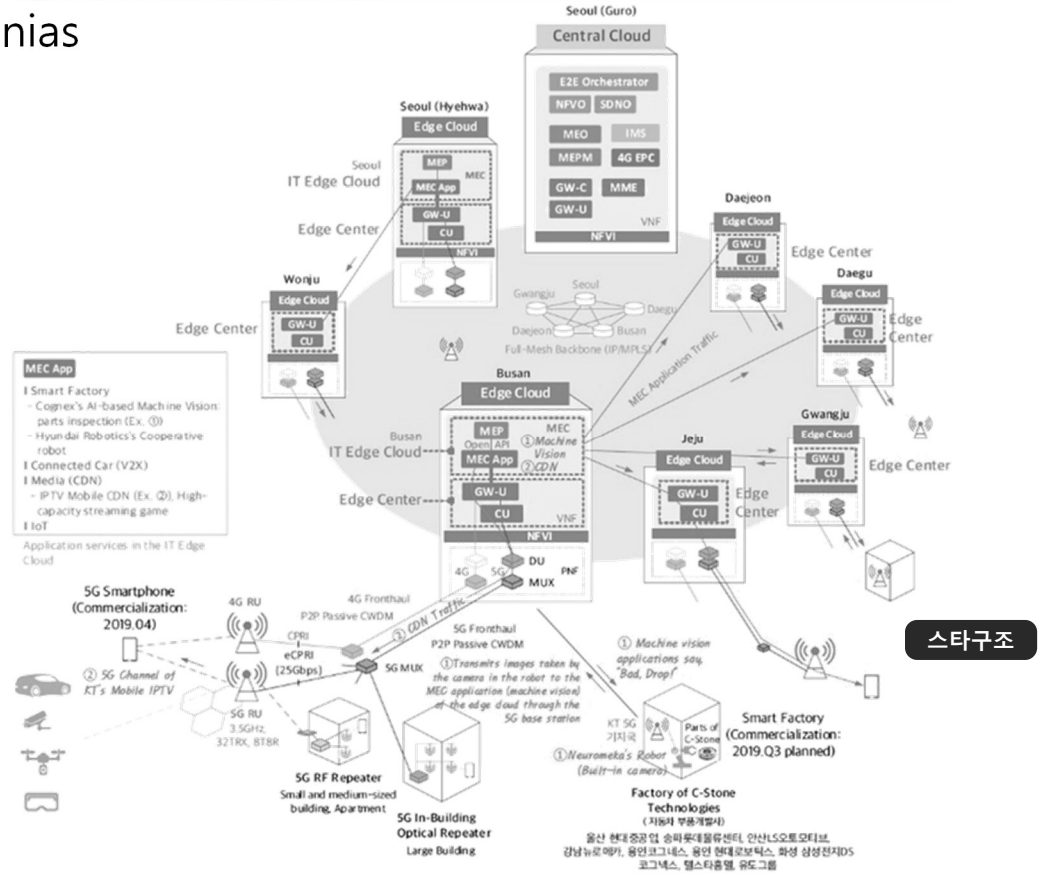
5G 주요 업체 List		
	주요 제품 및 사업	**주요 기업**
무선통신장비	안테나, RRH, RF부품	케이엠더블유, 에이스테크
	광트랜시버	오이솔루션
	프론트홀 장비	에치에프알, 쏠리드
	중계기	에치에프알, 쏠리드
	기지국 장비 케이스	서진시스템
	GaN트랜지스터	RFHIC
유선네트워크장비	FTTX, 스위치 장비	유비쿼스, 다산네트웍스, 에치에프알, 머큐리
	광트랜시버	오이솔루션
시험인증	인증	에이치시티
자료: 신한금융투자		

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

DAY 2: ENHANCED MOBILE BROADBAND

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

kt 5G VS SKT 5GX



스타구조

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

DAY 2: ENHANCED MOBILE BROADBAND

❖ 현재 통신사업자의 망 구성 (SKT) – by Netmanias

kt 5G VS SKT 5GX

센터 클라우드

2019. 07.18 발표

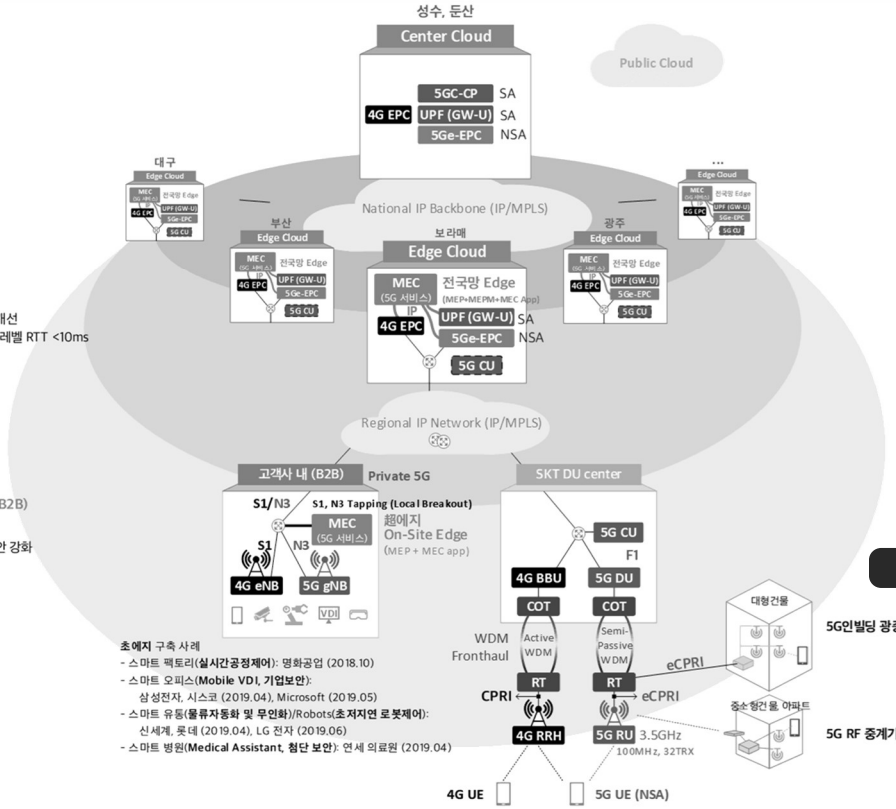
에지 클라우드 12개
(위치: 교환국)

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 민감 서비스
- 기업, 공공 데이터의 실시간 전처리 및 보안 강화
- Public Cloud와도

셀사이트



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

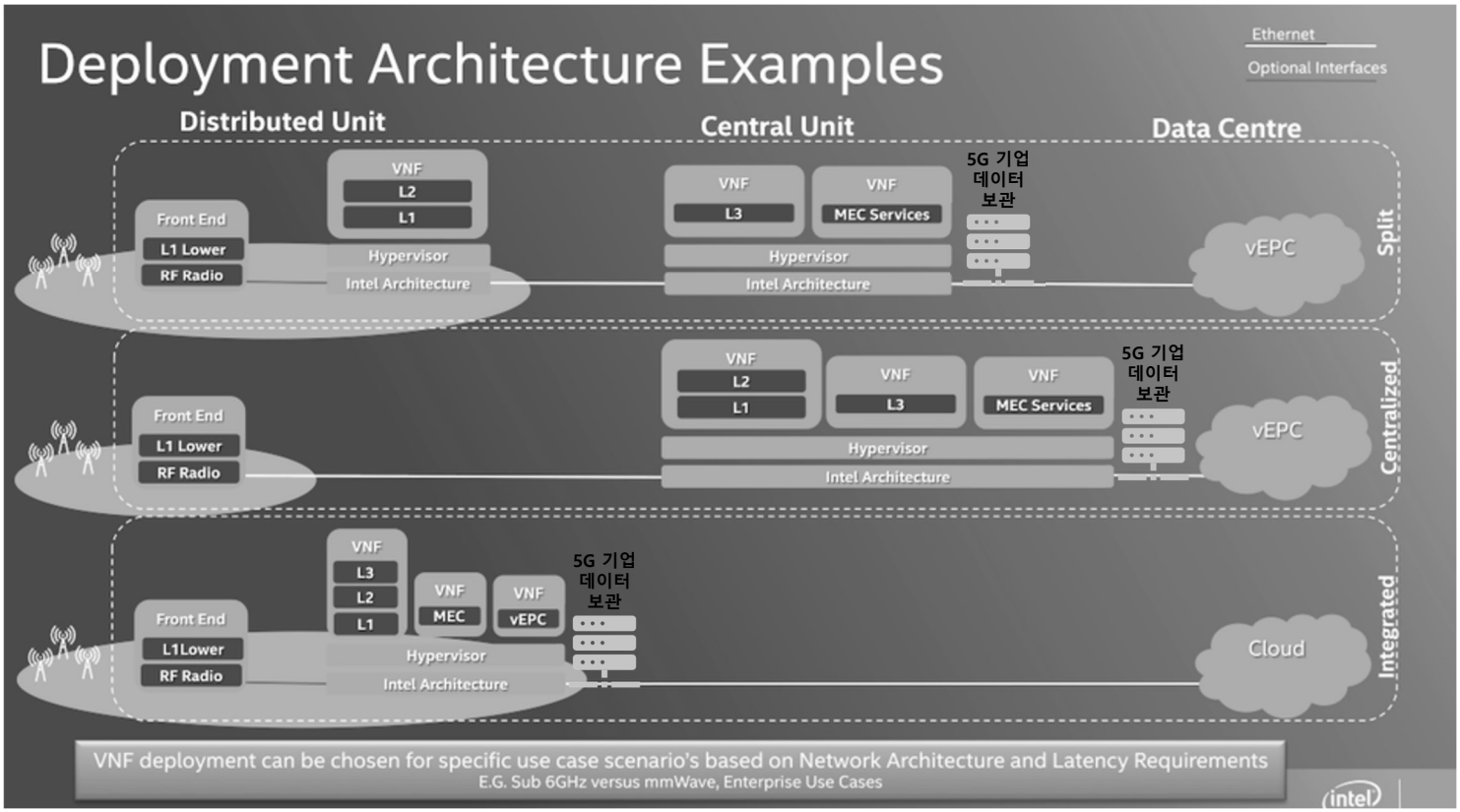
DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G RAN 구성 (예): 인텔의 FlexRAN

분할(Split)

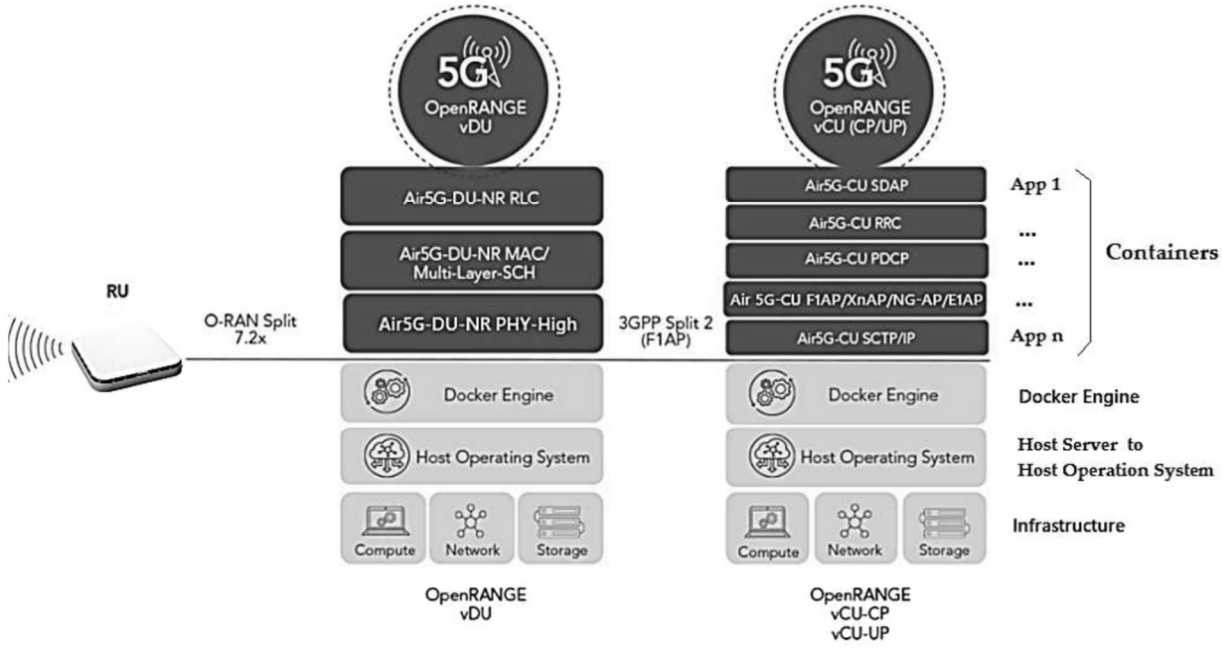
중앙집중(Centralized)

통합(Integrated)



DAY 2: ENHANCED MOBILE BROADBAND

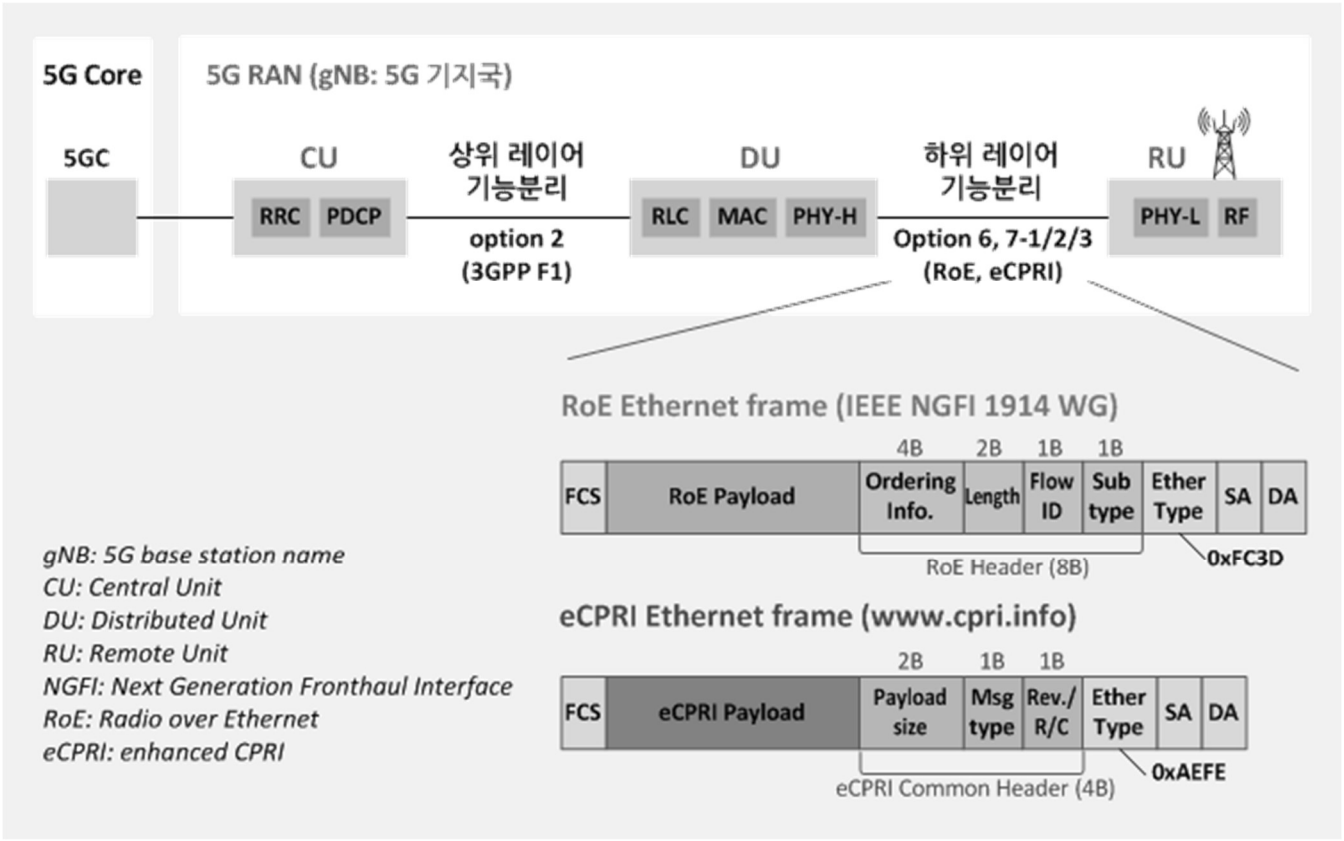
❖ vDU 및 vCU용 OpenRange 소프트웨어가 포함된 O-DU/O-CU 서버에서 실행되는 애플리케이션이 포함된 컨테이너 네트워크 기능(CNF) 아키텍처



Source: Airspan. Flexible Cloud Architecture with Powerful Openrange Software. Dynamic Fronthaul. pp. 1–39. Available online:https://www.airspan.com/openrange-software/ (accessed on 3 January 2023)

DAY 2: ENHANCED MOBILE BROADBAND

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

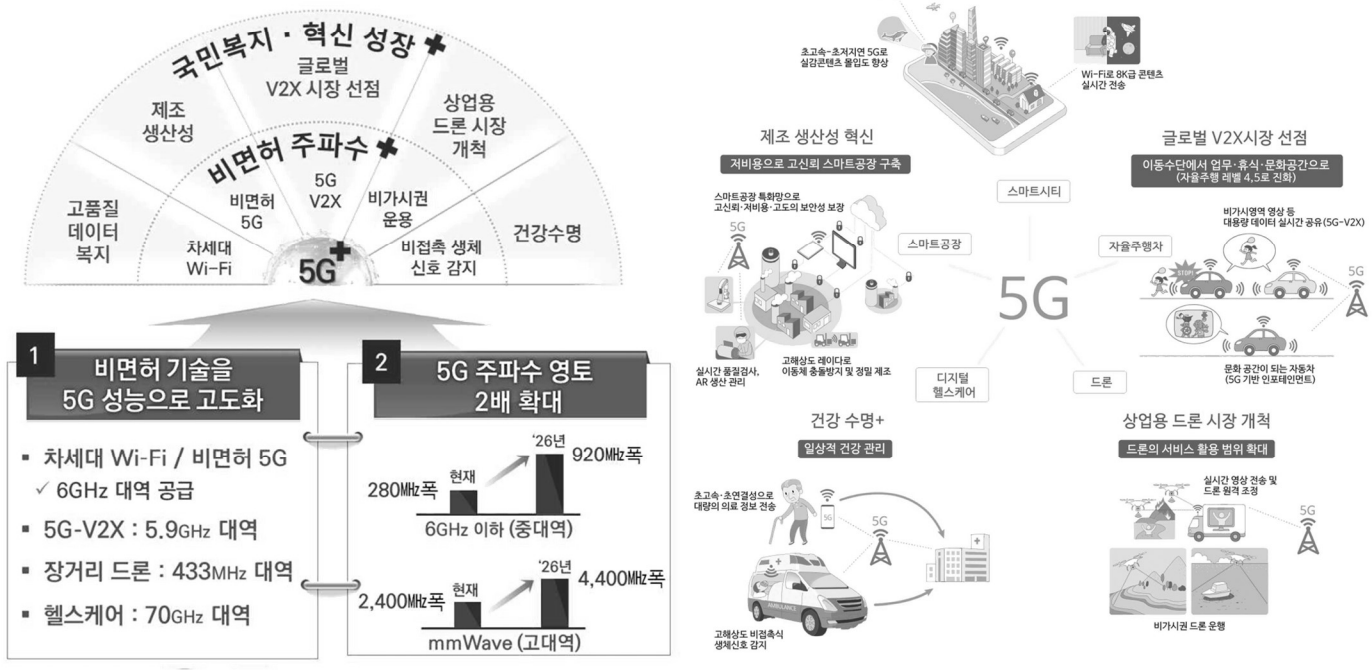


Source: 넷매니아즈

DAY 2: ENHANCED MOBILE BROADBAND

❖ 비면허 주파수 기술과 서비스

❖ 5G와 결합·보조하는 비면허 기술을 5G 성능으로 고도화 전략



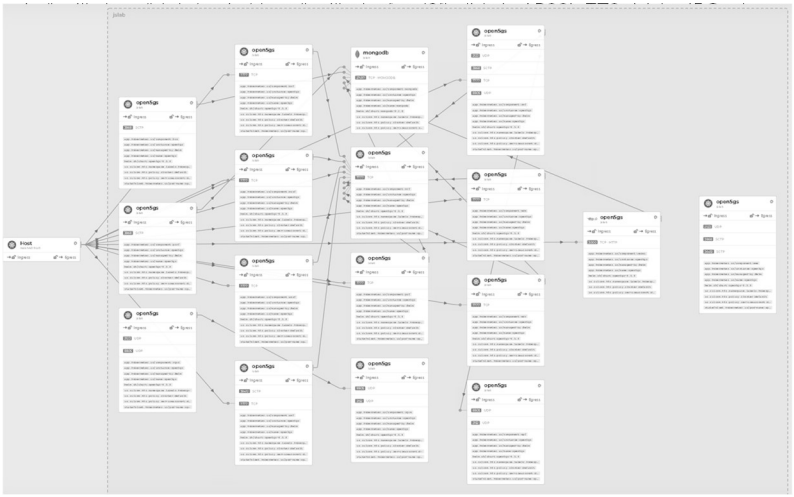
Source: 5G+ 스펙트럼 플랜, 과학기술정보통신부

DAY 2: ENHANCED MOBILE BROADBAND

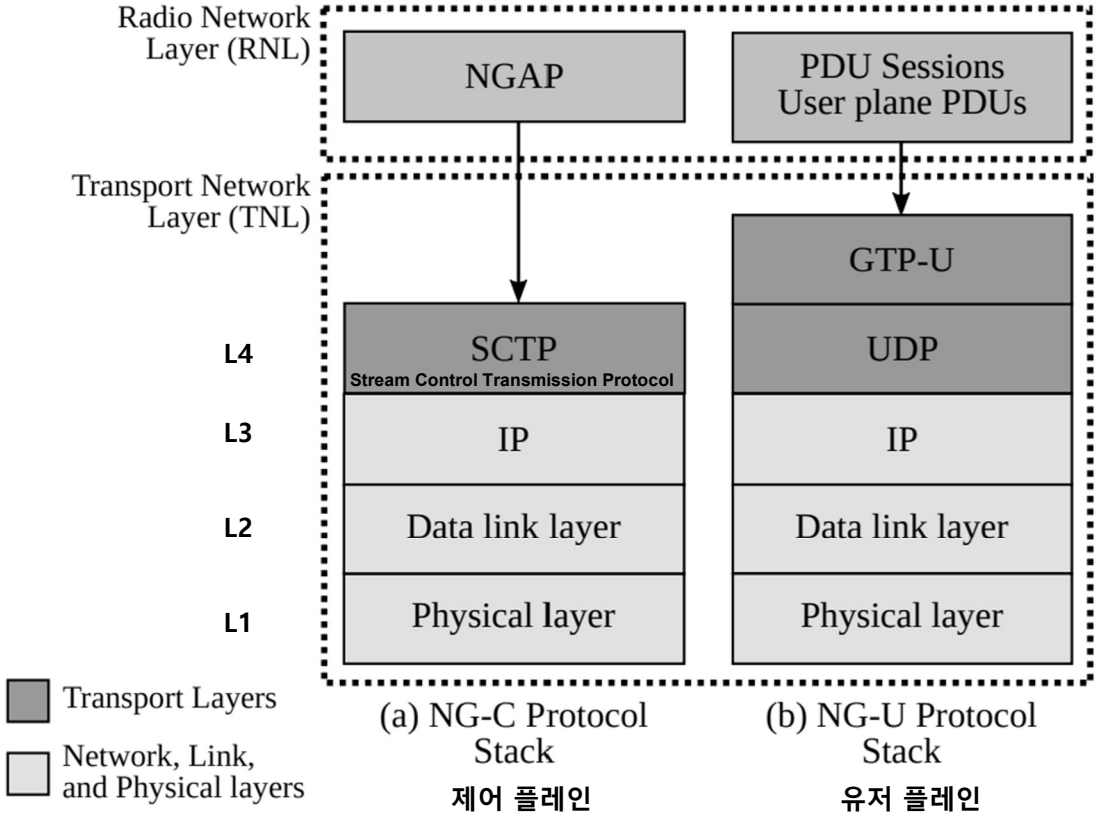
❖ NG-C 와 NG-U 프로토콜 스택

- 제어 플레인 (NG-C)
- 유저 플레인 (NG-U)

https://github.com/loxilb- https://github.com/loxilb-io/loxilbdocs



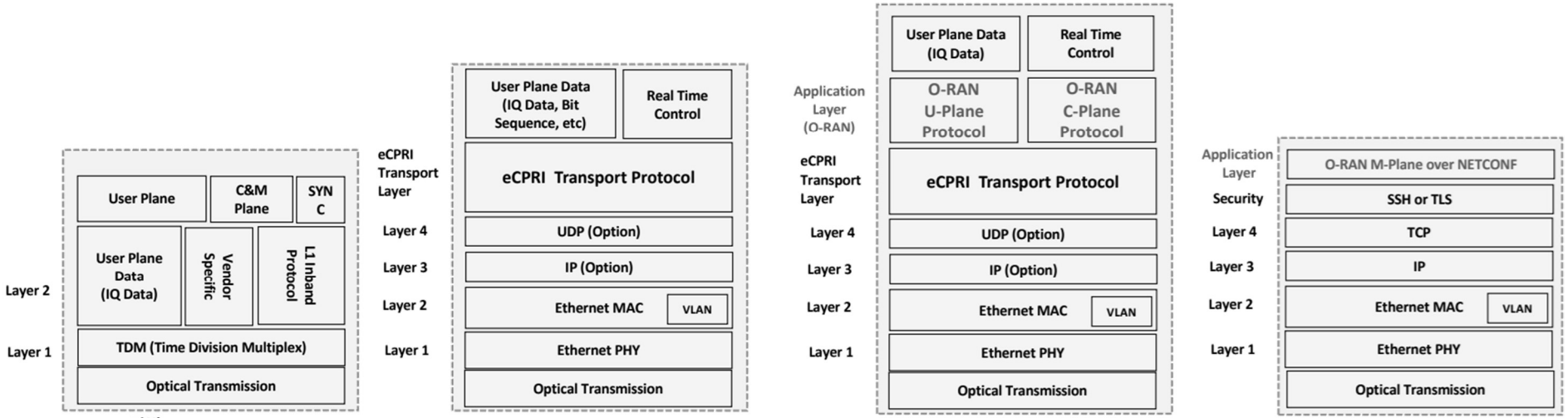
UE ←→ gNB ←→ UPF ←→ DN



Source: Tutorial on communication between access networks and the 5G core, IDLab—Department of Applied Engineering, University of Antwerp—IMEC, Antwerp, Belgium

DAY 2: ENHANCED MOBILE BROADBAND

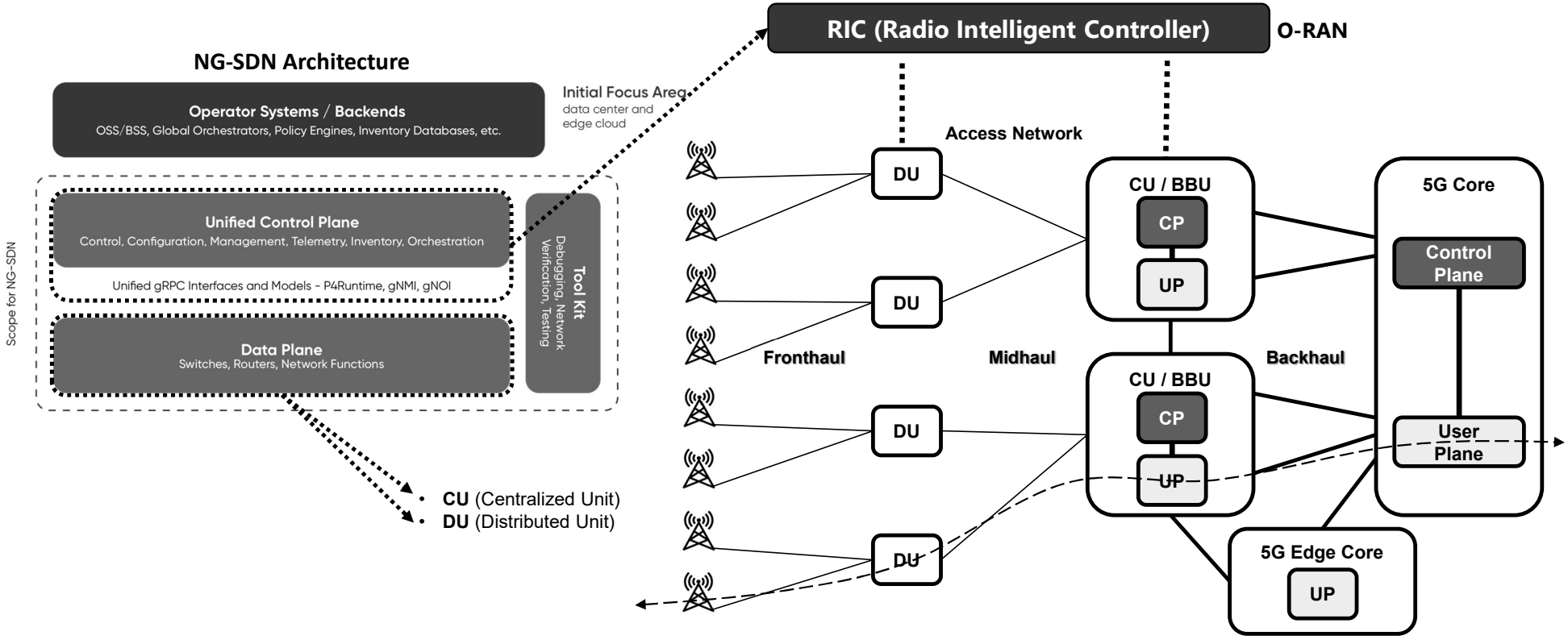
❖ 프론트홀 기술 간의 차이점 및 프로토콜 스택 비교



Source: Technological Trends in Open 5G Fronthaul, 이재승, 박재우, 이문식, 무선분산통신연구실, ETRI

DAY 2: ENHANCED MOBILE BROADBAND

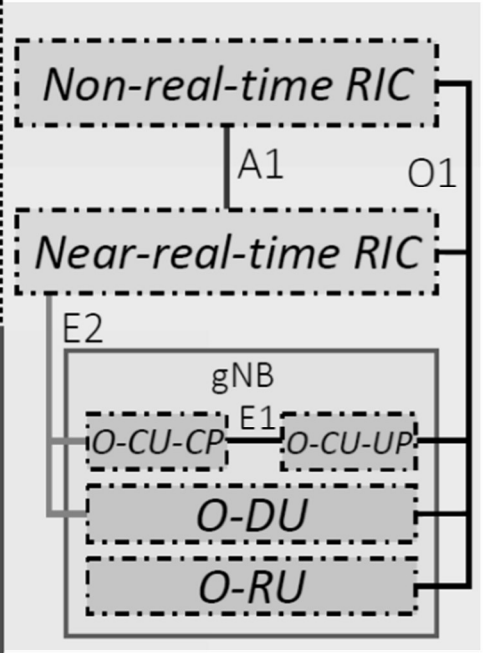
❖ O-RAN과 '프론트홀/미드홀/백홀'



DAY 2: ENHANCED MOBILE BROADBAND

❖ **O-RAN architecture, applications and control loops.**

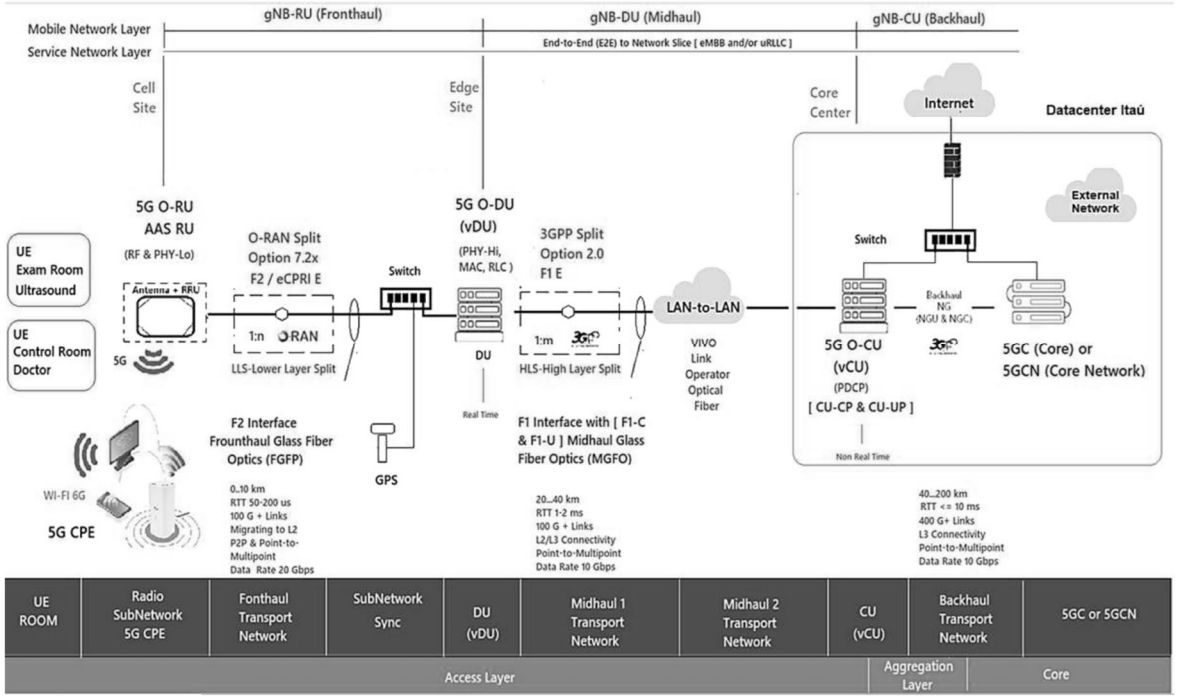
Control objective	Input data	Timescale and Apps
Policies, models, slicing	Aggregated KPMs	Non-real-time > 1 s **rApps**
Radio Resource Management, Session Management	CU-level and MAC-level KPMs	Near-real-time 10-1000 ms **xApps**
Beamforming, Scheduling, Puncturing, Interference and Modulation Management **Focus of this paper**	MAC/PHY-level KPMs, I/Q samples, Packets	Real-time < 10 ms **dApps**



Source: https://arxiv.org/pdf/2203.02370v1.pdf, dApps: Distributed Applications for Real-time Inference and Control in O-RAN, Salvatore D'Oro, Michele Polese, Leonardo Bonati,

DAY 2: ENHANCED MOBILE BROADBAND

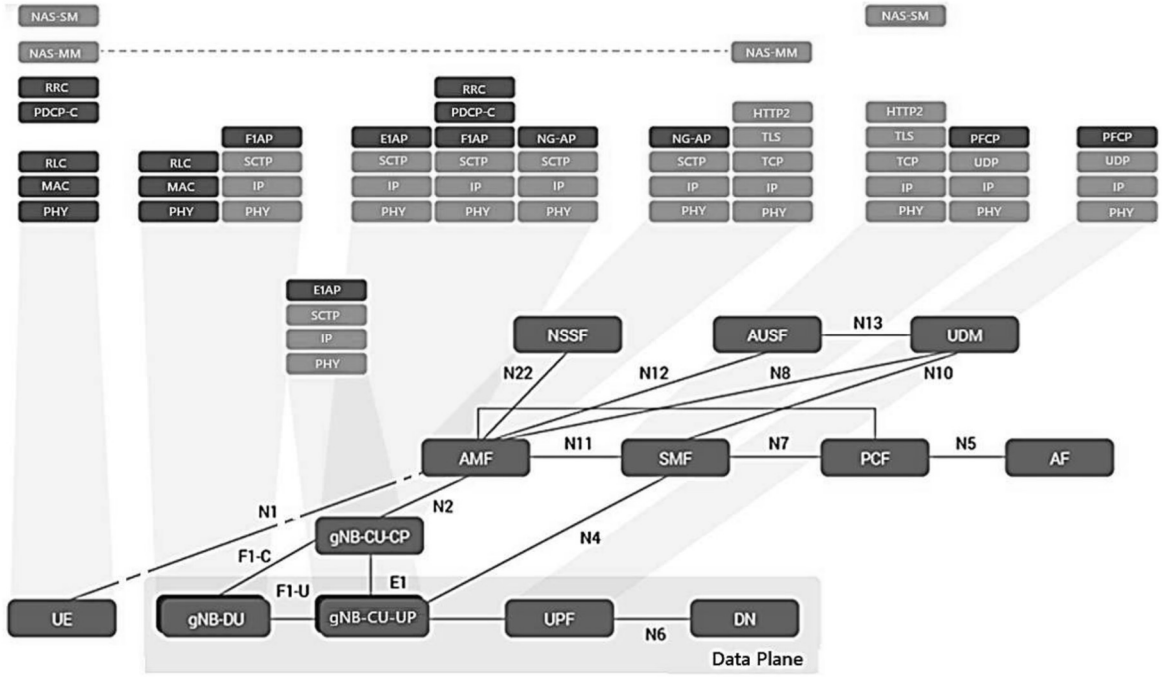
❖ 인프라, 모바일 및 서비스 레이어에서 vRAN을 제공하는 O-RAN OAM을 갖춘 Inovac OpenCare5G의 5G xHaul 네트워크 아키텍처



Source: OpenCare5G: O-RAN in Private Network for Digital Health Applications, Dr. Giuseppe Caso, Prof. Dr. Özgü Alay, Prof. Dr. Anna Brunstrom, Dr. Harilaos Koumaras, Dr. Almudena Díaz Zayas

DAY 2: ENHANCED MOBILE BROADBAND

❖ **Architecture of the core 5G SBA and reference point with the end-to-end control plane protocol stack and its main interfaces.**



Source: Bhat, R.R. Addressing Security for 5G Cloud Radio Access Networks. 2019. Available online: https://www.a10networks.com/blog/addressing-security-for-5g-cloud-radio-access-networks/

DAY 2: ENHANCED MOBILE BROADBAND

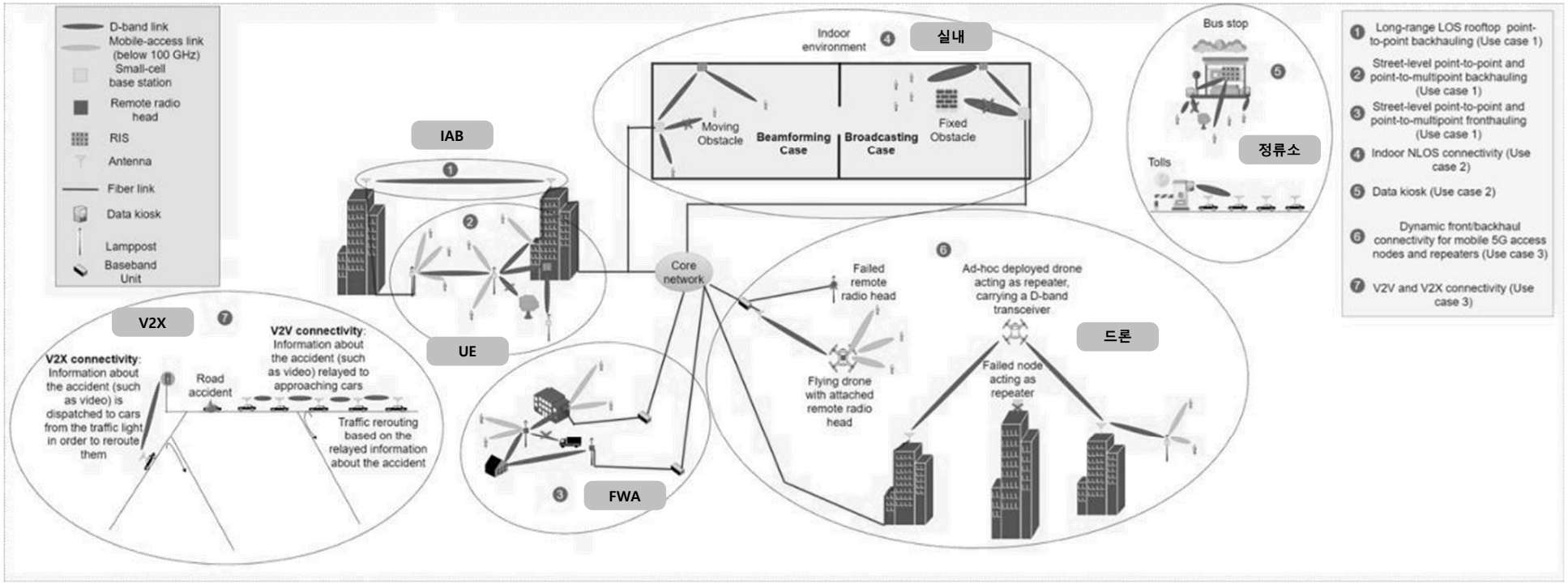
❖ O-RAN Alliance의 각 WG별 담당분야

WG 이름	담당분야
WG1(Use Cases and Overall Architecture Workgroup)	O-RAN 전체 구조 및 Use Case 정의, 각 WG별 표준화 역할 배분
WG2(Non-real-time RAN Intelligent Controller and A1 Interface Workgroup)	RAN에 대한 비실시간(Non-real-time) 지능형 무선 자원 관리, 상위 레이어 절차 최적화 및 정책 최적화 등을 지원하는 Non-real-time RIC 및 AI/ML 모델 제공과 피드백 수집을 위한 A1 인터페이스 개발
WG3(Near-real-time RIC and E2 Interface Workgroup)	RAN 구성 요소 및 자원을 실시간에 가깝게(Near-real-time) 제어하고 최적화할 수 있는 Near-real-time RIC 및 E2 인터페이스 개발
WG4(Open Fronthaul Interfaces Workgroup)	멀티 벤더 간 호환이 가능한 개방형 프론트홀 인터페이스(O-DU와 O-RU 사이의 인터페이스 규격) 개발
WG5(Open F1/W1/E1/X2/Xn Interface Workgroup)	F1/W1/E1/X2/Xn 인터페이스를 위한 멀티 벤더 프로파일 규격(O-CU 및 O-DU 사이의 인터페이스와 관련된 프로파일) 개발
WG6(Cloudification and Orchestration Workgroup)	Near-real-time RIC, O-CU, O-DU 등에 대해 RAN 하드웨어와 소프트웨어를 분리하여 RAN 가상화를 실현할 수 있도록 하기 위한 클라우드 플랫폼에 대한 참조 구조 개발
WG7(White-box Hardware Workgroup)	화이트박스 기반의 개방형 기지국의 하드웨어 참조 디자인 개발
WG8(Stack Reference Design Workgroup)	O-CU 및 O-DU를 위한 소프트웨어 구조 및 참조 디자인 개발
WG9(Open X-haul Transport Workgroup)	이더넷 인터페이스 기반의 프론트홀, 미드홀, 백홀에서의 전송 기술을 담당하며 PON, xWDM, DOCSIS 등에 대한 기술 요구사항, 아키텍처 등을 정의
WG10(OAM Workgroup)	관리 인터페이스인 O1 인터페이스 OAM(Operation Administration Maintenance) 규격 개발

Source: Technological Trends in Open 5G Fronthaul, 이재승, 박재우, 이문식, 무선분산통신연구실, ETRI

DAY 2: ENHANCED MOBILE BROADBAND

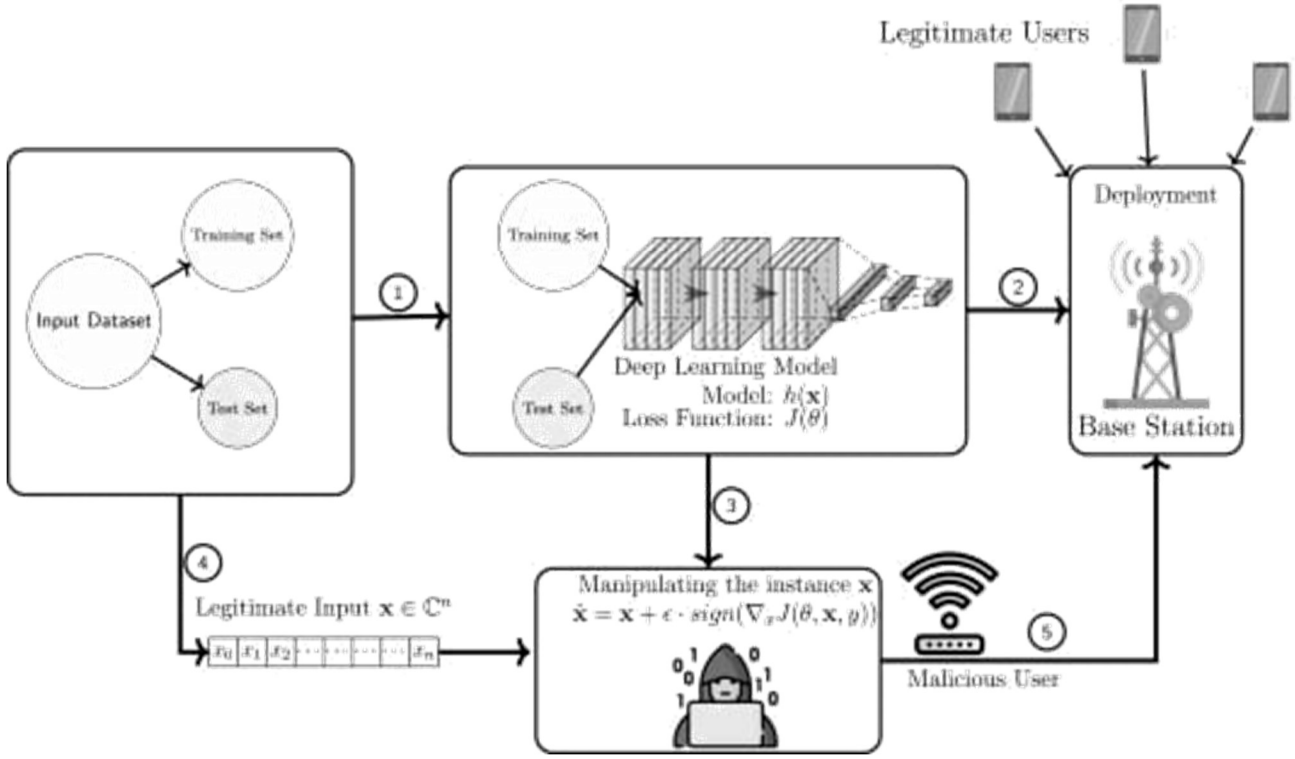
❖ 재구성 가능한 표면 배포 시나리오 (Reconfigurable surfaces deployment scenarios)



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

DAY 2: ENHANCED MOBILE BROADBAND

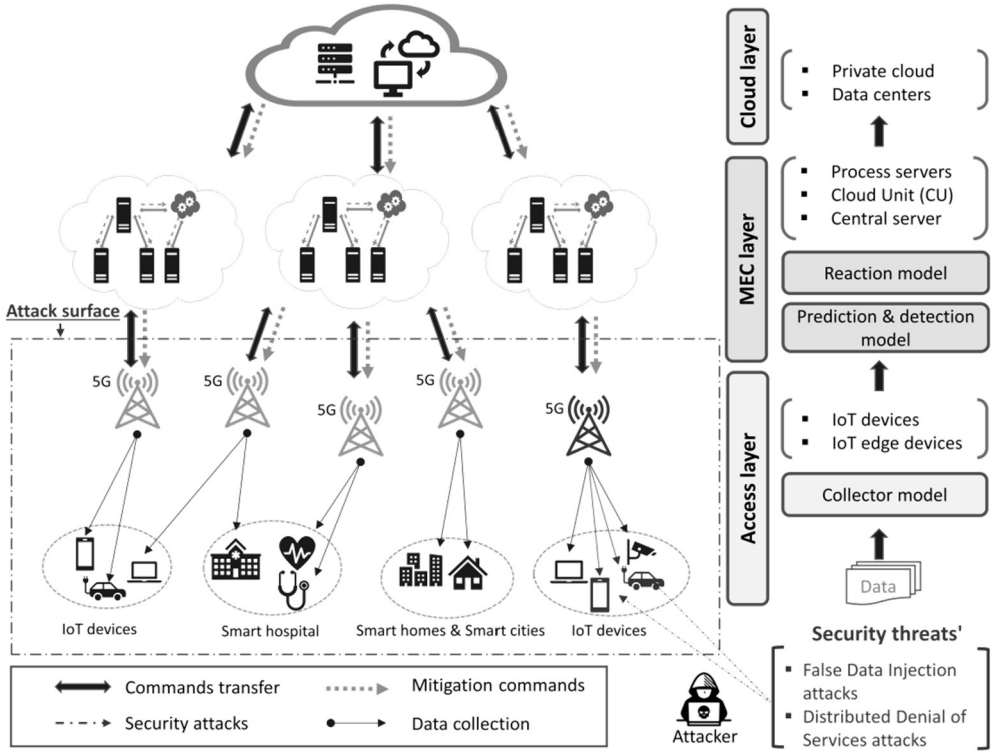
❖ 밀리미터파 빔 예측에서 6G 네트워크용 머신 러닝 솔루션에 대한 보안 문제



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

DAY 2: ENHANCED MOBILE BROADBAND

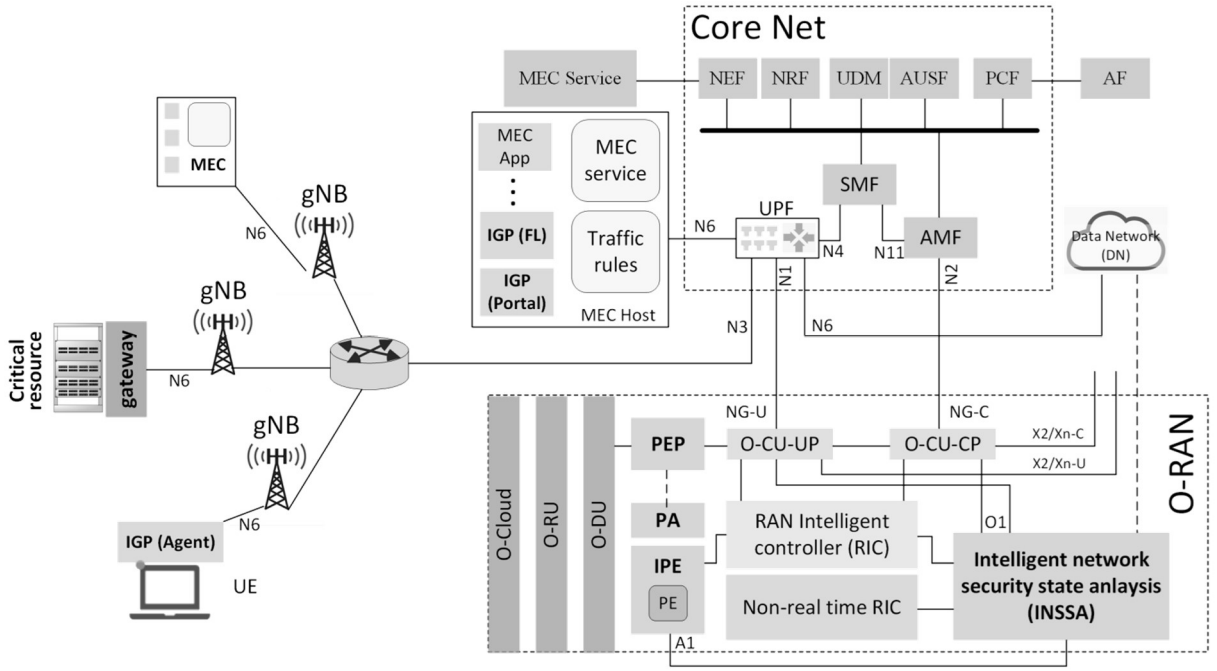
❖ 5G 지원 IoT에서 FDIA(False Data Injection Attack) 및 DDoS 공격 예측 및 탐지



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

DAY 2: ENHANCED MOBILE BROADBAND

❖ **5G/6G 네트워크를 위한 지능형 제로 트러스트 아키텍처(iZTA): O-RAN의 맥락에서 머신 러닝의 원칙, 과제 및 역할**



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

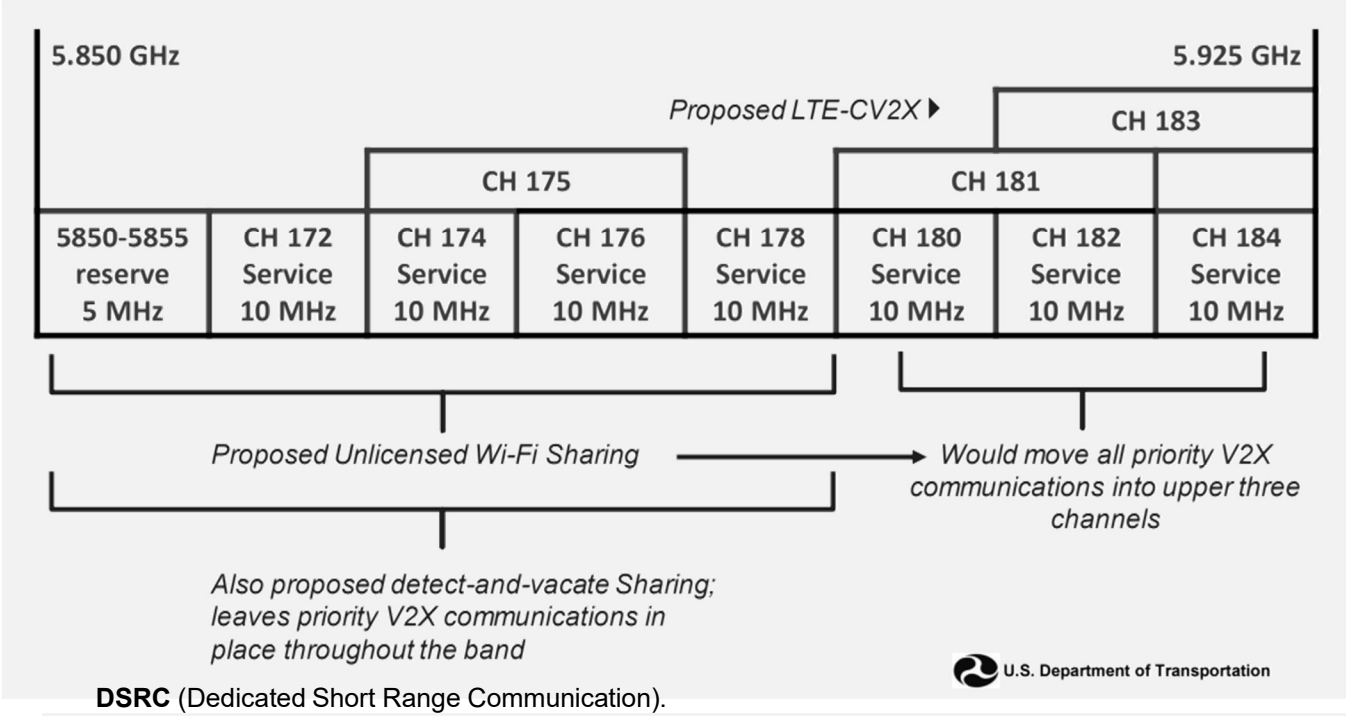
❖ V2X Standards (L1 & L2)

	5G NR V2X (sidelink)	LTE V2X (sidelink)	802.11p
Max. Bandwidth @ sub 6GHz	40 MHz (Flexible) (>150Mbps)	20 MHz (~ 70 Mbps)	20 MHz (54 Mbps)
ITS channel (Korea)	-	-	Multichannel 10 MHz
ITS channel (US*)	-	20 MHz	10 MHz
Comm. Type	Broadcast, Groupcast, Unicast	Broadcast	Broadcast
Retransmission	HARQ	HARQ (blind)	-
Resource Selection	Mode 1 (gNB centralized) Mode 2 (UE sensing based)	Mode 3 (eNB centralized) Mode 4 (UE sensing based)	*CSMA-CA*
Modulation	QPSK, 16QAM, 64QAM, 256QAM	QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Channel Coding	LDPC / Polar	Turbo	Convolutional
Waveform	OFDM	SC-FDM	OFDM

Source: US FCC Nov. 2019. US FCC FNPRM Oct. 28 2020 will be explained later session

DAY 2: ENHANCED MOBILE BROADBAND

❖ **US 5G NR V2X case**



DSRC (Dedicated Short Range Communication).

V2X용으로 할당되었던 5.9GHz 대역 7개 채널 중 하위 4개 채널을 WiFi에 할당하고 상위 3개 채널을 C-V2X에 할당

DAY 2: ENHANCED MOBILE BROADBAND

❖ **V2X: Vehicle-to-Anything communication**

Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

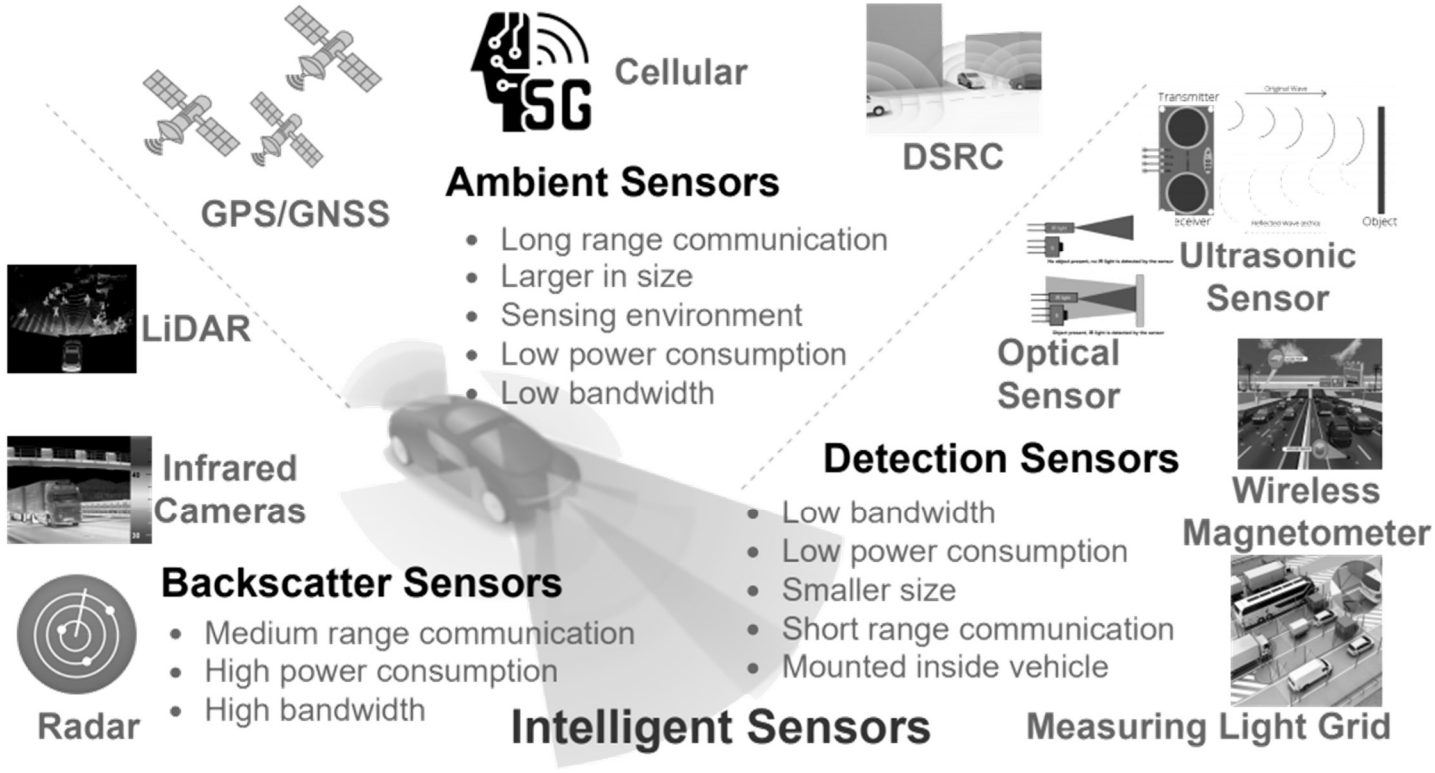
❖ 온보드 센서 유형, 범위 및 사용법

Sensor Type	Range	Example	Usage
Proximity sensors	5 m	Ultrasonic sensor	Detects nearby obstacles Parking assistance
Short range sensors	30 m	Forward camera Backward camera Short range radars	Recognition of traffic signs Detection of blind spots Alerting cross traffic Lane detection
Medium range sensors	80-160 m	LiDAR Medium range radars	Detection of pedestrians Collision avoidance
Long range sensors	250 m	Long range radars	Support adaptive cruise control Information collection at high speed

Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

DAY 2: ENHANCED MOBILE BROADBAND

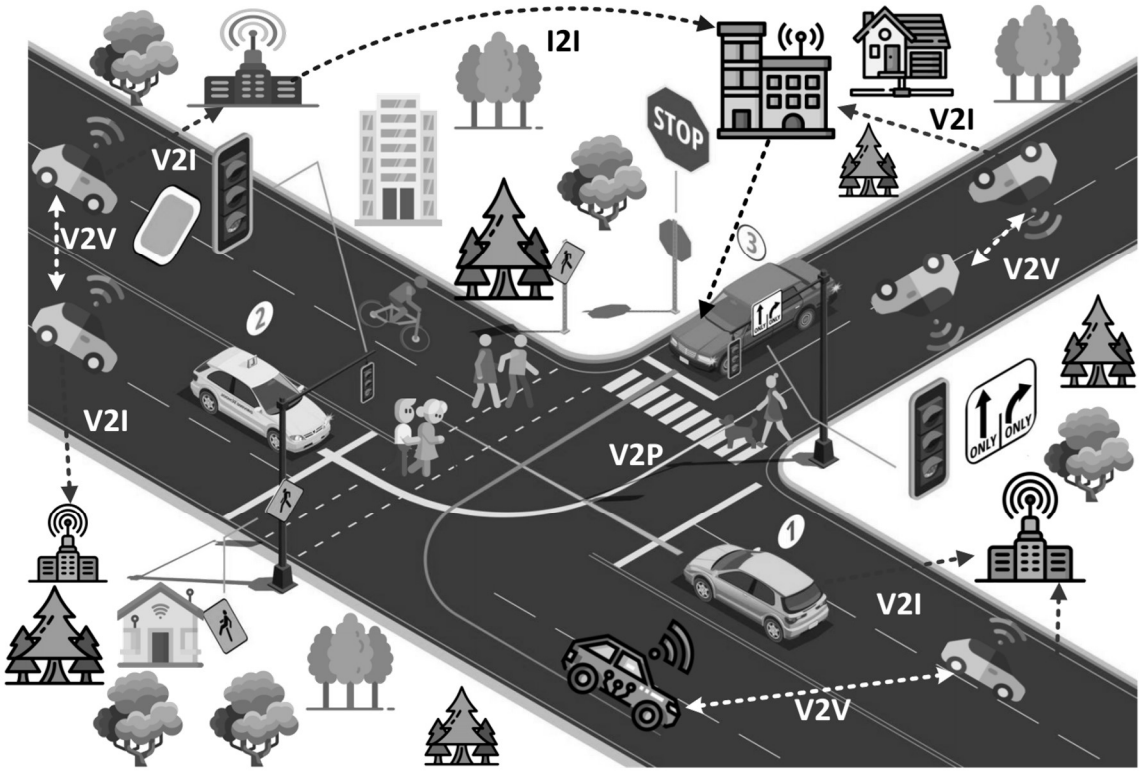
❖ 자율 주행 및 커넥티드 차량의 지능형 센서



Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

DAY 2: ENHANCED MOBILE BROADBAND

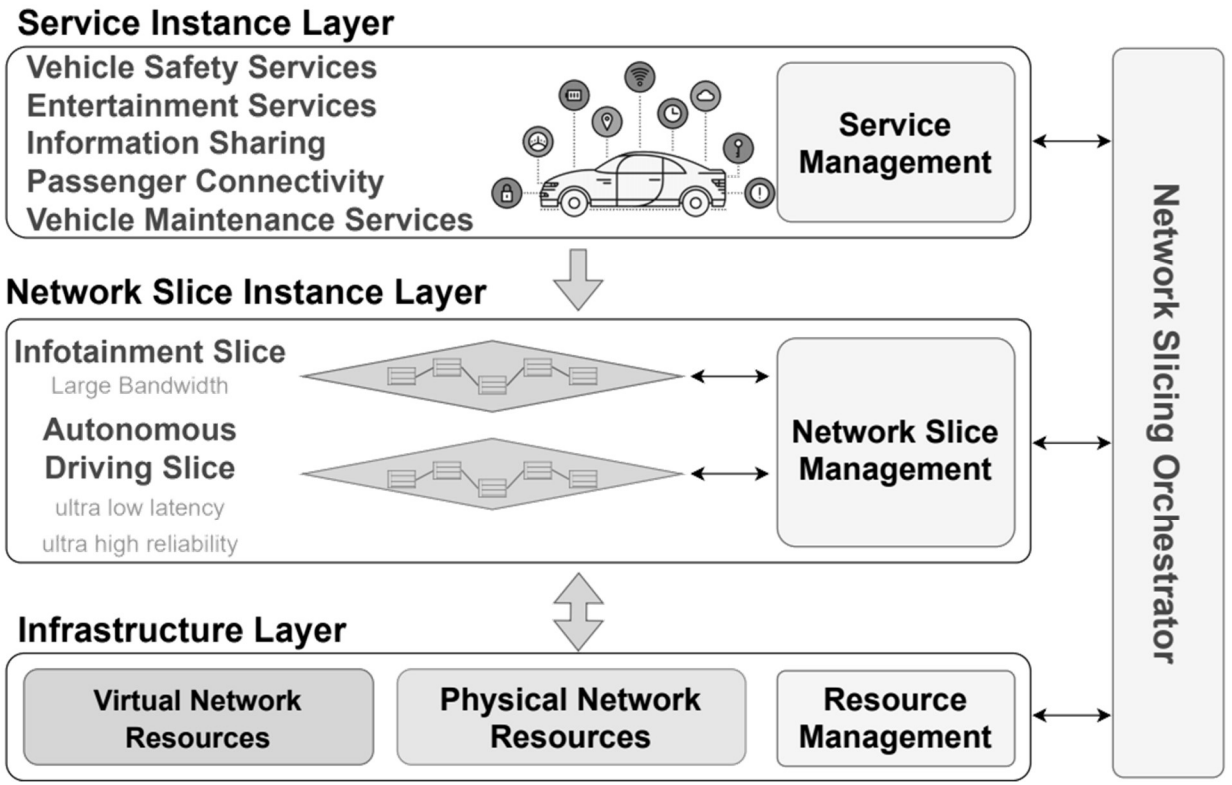
❖ 자율 주행 커넥티드 차량, 인프라, 환경 및 통신



Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

DAY 2: ENHANCED MOBILE BROADBAND

❖ ACV(자율주행 및 커넥티드 차량)를 위한 네트워크 슬라이싱



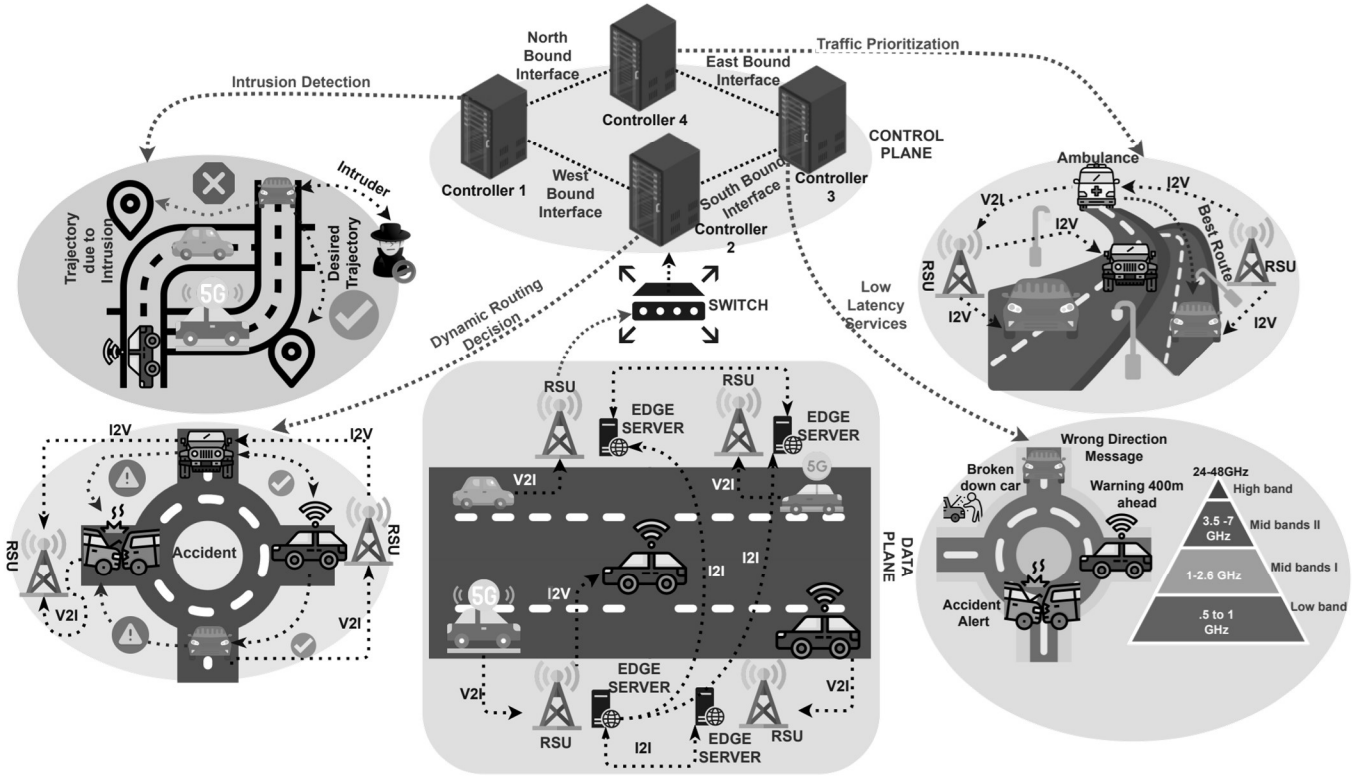
ACV (Autonomous and Connected Vehicles)

Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G 지원 SDN이 ACV에 미치는 영향

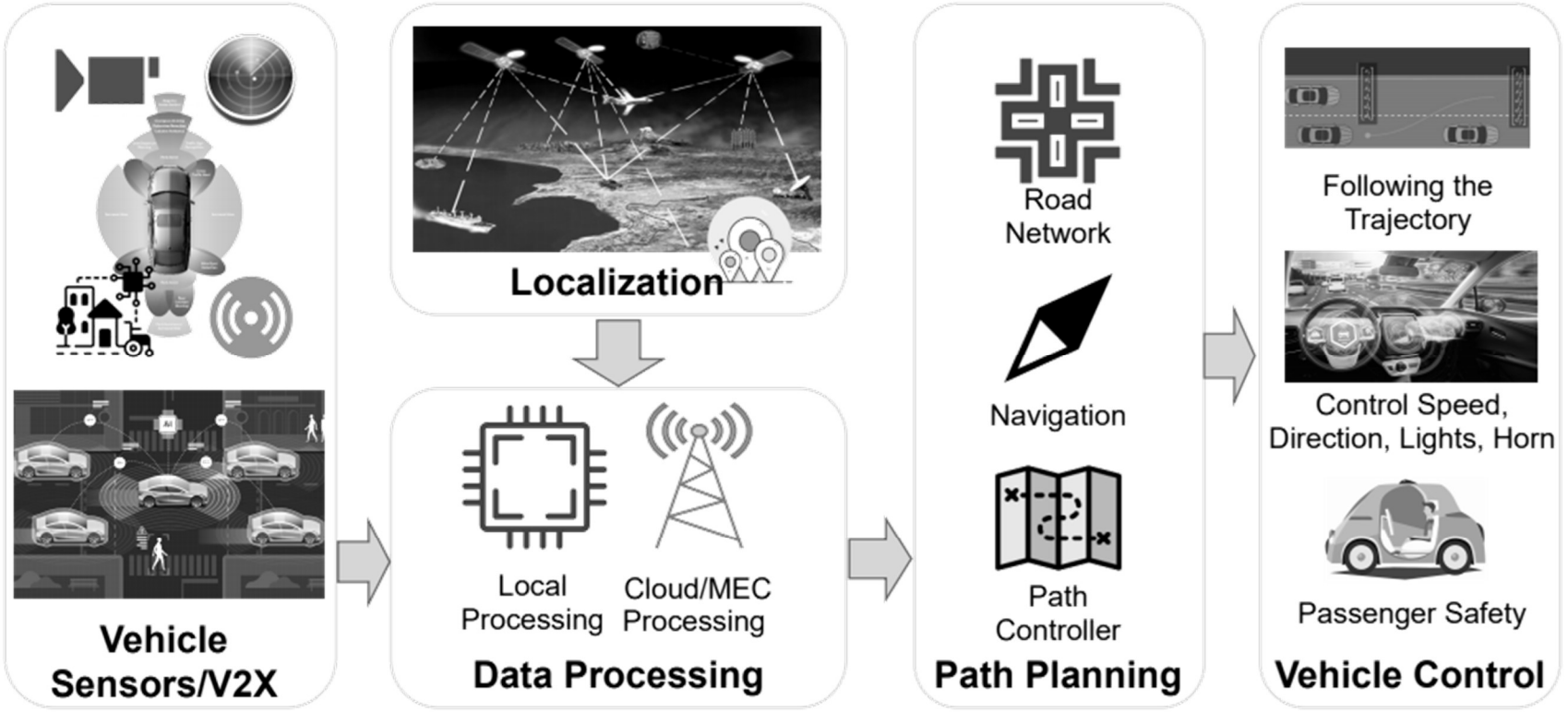
- 침입 탐지
- 다이나믹 경로 결정
- 저지연 서비스
- 트래픽 우선순위



Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

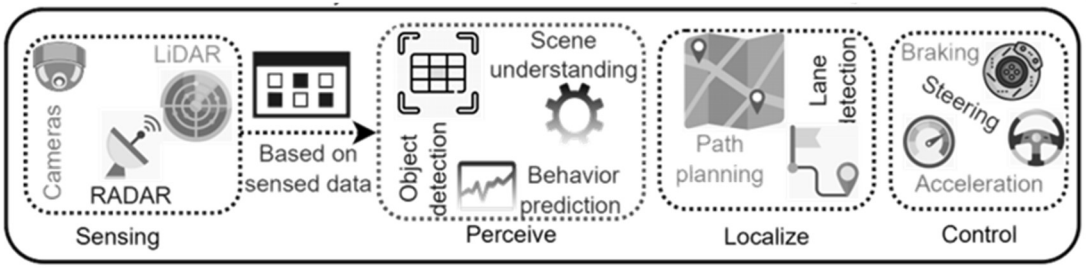
DAY 2: ENHANCED MOBILE BROADBAND

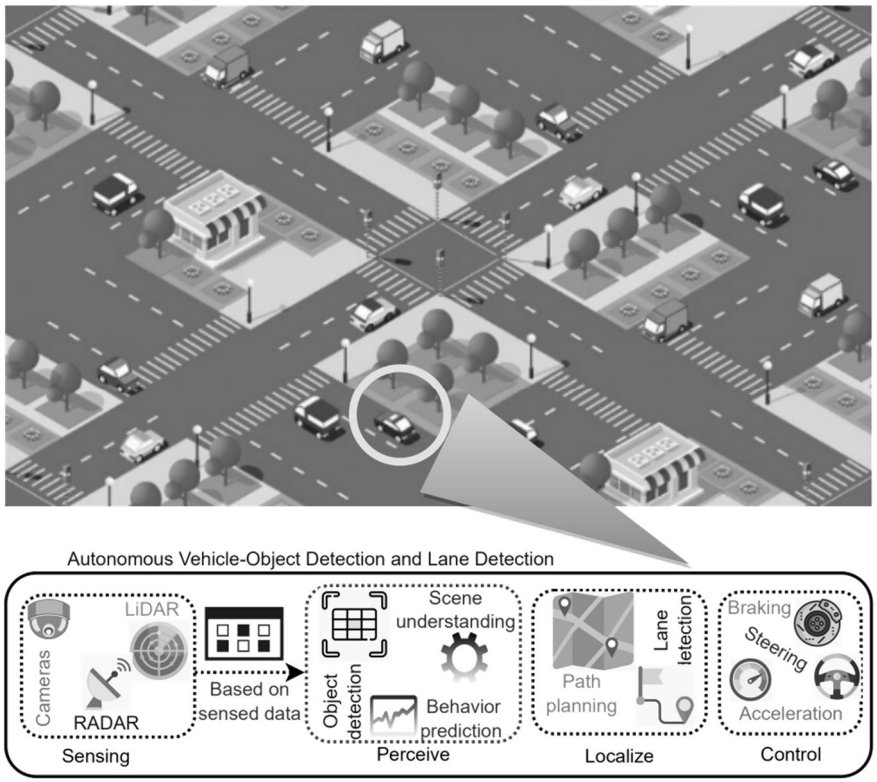
❖ AV 데이터 수집, 데이터 처리, 경로 계획 및 차량 제어



Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

❖ 자율주행 차량의 물체 감지





Source: Autonomous Vehicles in 5G and Beyond: A Survey, Saqib Hakak, Thippa Reddy Gadekallu, Swarna Priya Ramu, Parimala M, Praveen Kumar Reddy Maddikunta, (arXiv:2207.10510v1)

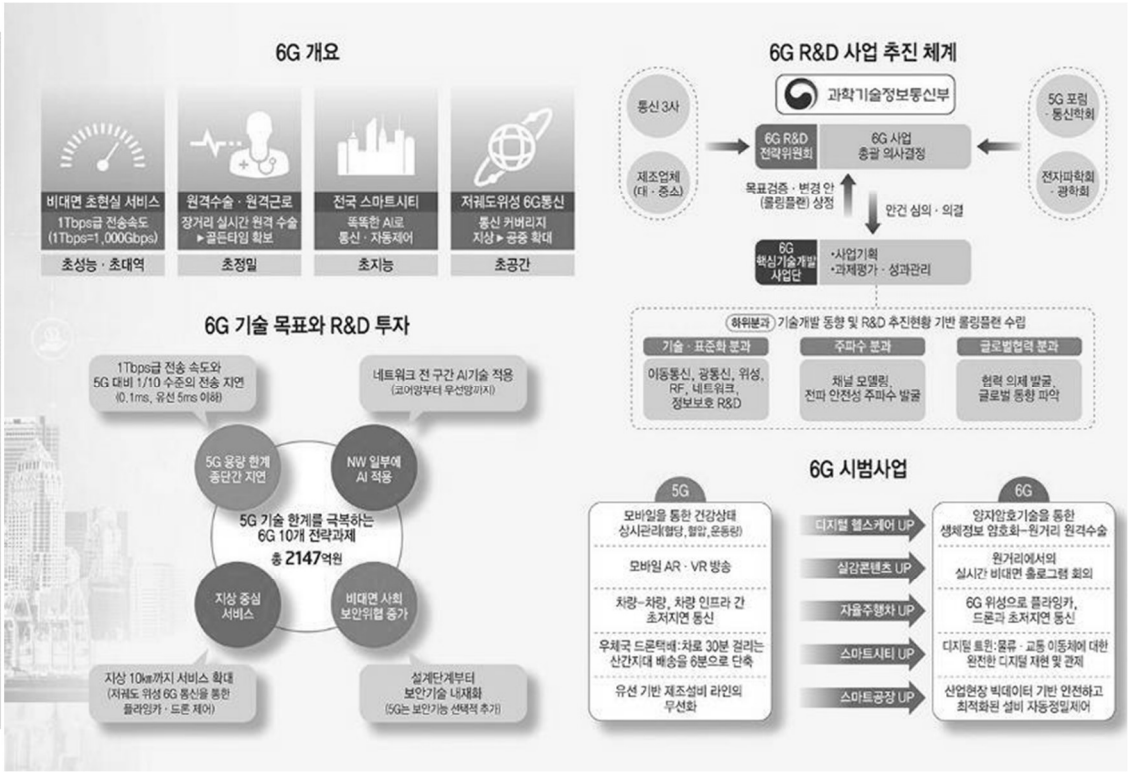
DAY 2: ENHANCED MOBILE BROADBAND

❖ 과기부 - 6G 6대 중점 개발 분야 & 10대 전략과제

< 6G 핵심기술개발 주요 내용 >

기존 기술(5G)의 한계	중점분야	전략과제	주요 성과물
융합 서비스 실현 한계 * 5G 전송속도(20Gbps)로는 다수가 이용하는 초고속 융합서비스 보편화에 한계 - 자율주행, 실감 AR/VR 등	초성능	⊙ 1Tbps급 전송속도 실현 * 1Tbps = 1,000Gbps	
		1. Tbps 무선통신	Tbps급 무선통신 기술
		2. Tbps 광통신	Tbps급 광통신 기술
	초대역	⊙ Tbps급 전송속도를 실현할, 100~300GHz 주파수 대역도 포함 * 5G는 100GHz 이하에서만 주파수 발굴	
		3. ㎔ RF 부품	고출력 저잡음 전력증폭기, Sub THz 트랜시버
		4. ㎔ 주파수	대역별 전파모델 및 DB
유선, 종단간 지연 미고려 * (5G 지연) 무선구간 10→1ms / 유선구간 여전히 수십ms	초정밀	⊙ 유·무선 지연시간 단축 (무선 0.1msec, 유선 5msec) * 5G는 무선 1msec, 유선 수십msec	
		7. 종단간 초정밀 네트워크	초저지연, 고정밀 패킷 포워딩 H/W 모듈
공간활용 커버리지 미고려 * 지상 최대 120m, KTX급 이동성 지원	초공간	⊙ 지상 10Km까지 서비스 확대(위성 활용 플라잉카, 드론 수용) * 5G는 지상 중심 서비스	
		5. 공간 이동통신	3D 이동체 프로토콜SW
		6. 공간 위성통신	위성/지상 통합 액세스 및 탑재체 기술
AI 적용 초기단계 * 현 AI의 5G 적용기술은 코어망에만 적용, 무선구간은 미지원	초지능	⊙ 네트워크 전 구간에 진화된 AI 기술 적용(코어망+무선구간) * 5G는 네트워크 일 부분에 AI 적용	
		8. 지능형 무선 액세스	자동화 및 지능형 시스템
		9. 지능형네트워크	
보안 기능 지속적 추가 필요 * 5G 표준은 최소한의 보안기능만 규격화	초신뢰	⊙ 6G 설계 단계부터 보안기술을 내재화(Embedded) * 5G는 환경변화에 따라 보안기능을 선택적으로 추가(Add-On)	
		10. 6G품질상시보장 보안기술	6G 품질을 보장하는 내재화된 보안기술

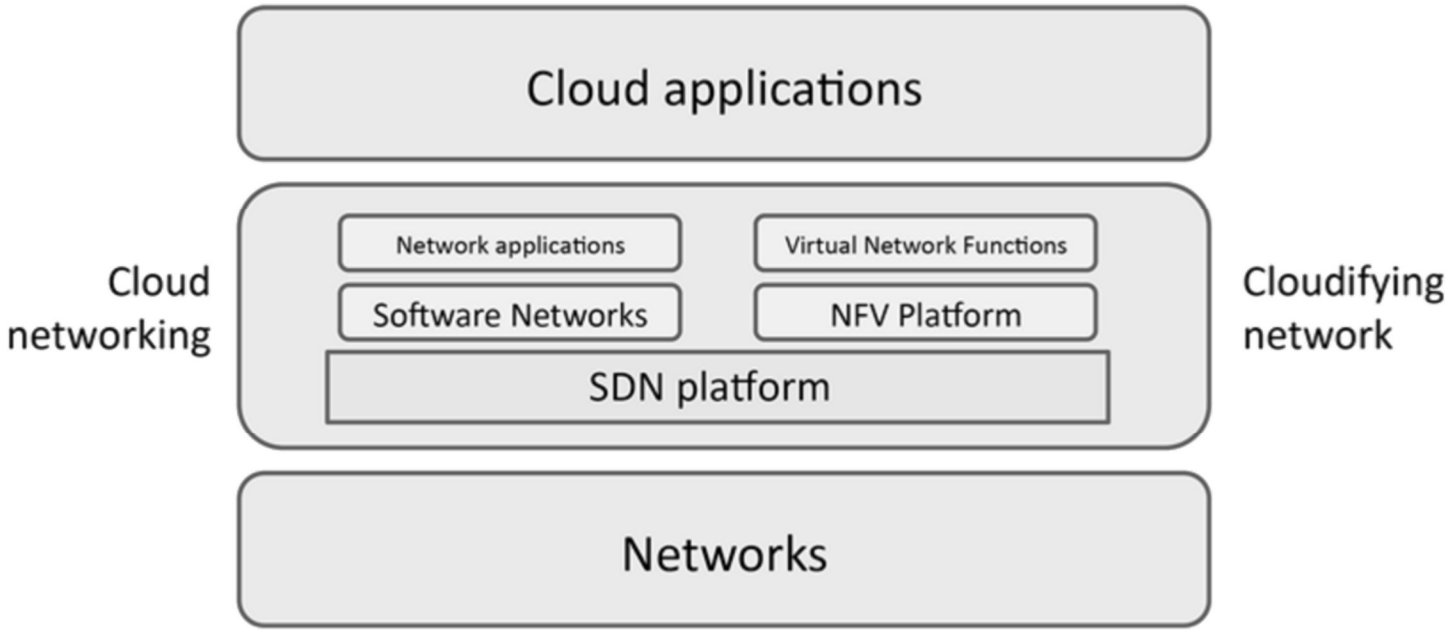
6G 핵심기술개발 주요내용 [자료=과학기술정보통신부]



Source: 과기부

❖ SDN

- **SDN 솔루션 아키텍처의 개요**

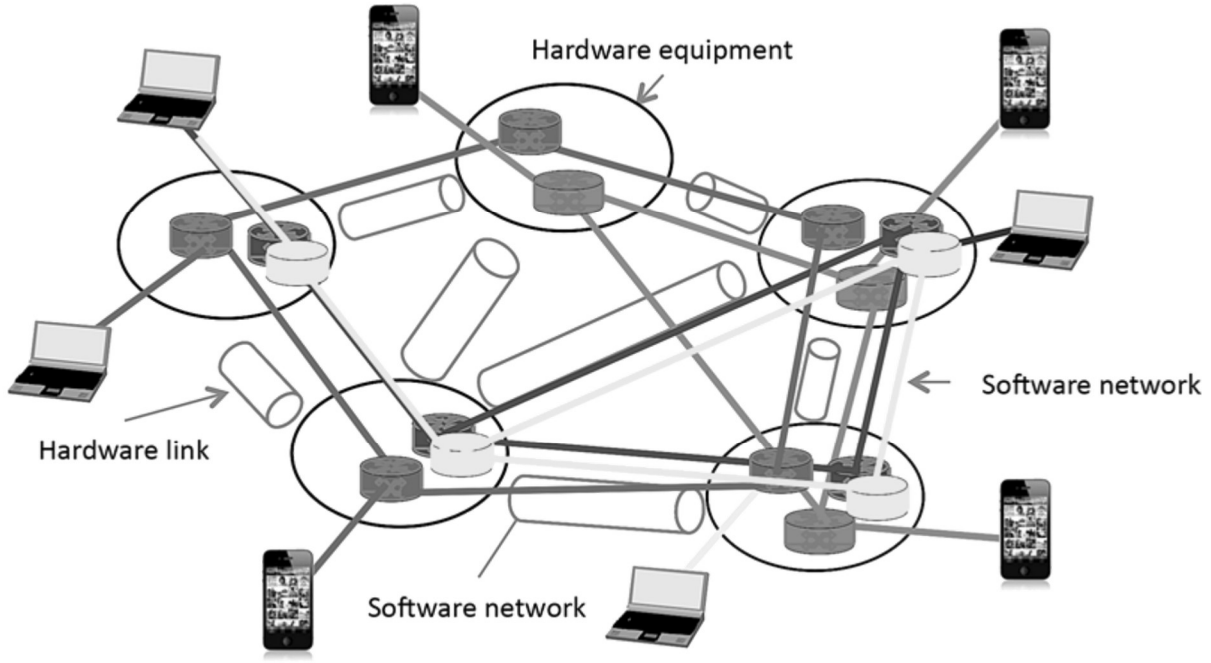


Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

DAY 2: ENHANCED MOBILE BROADBAND

❖ Virtualization

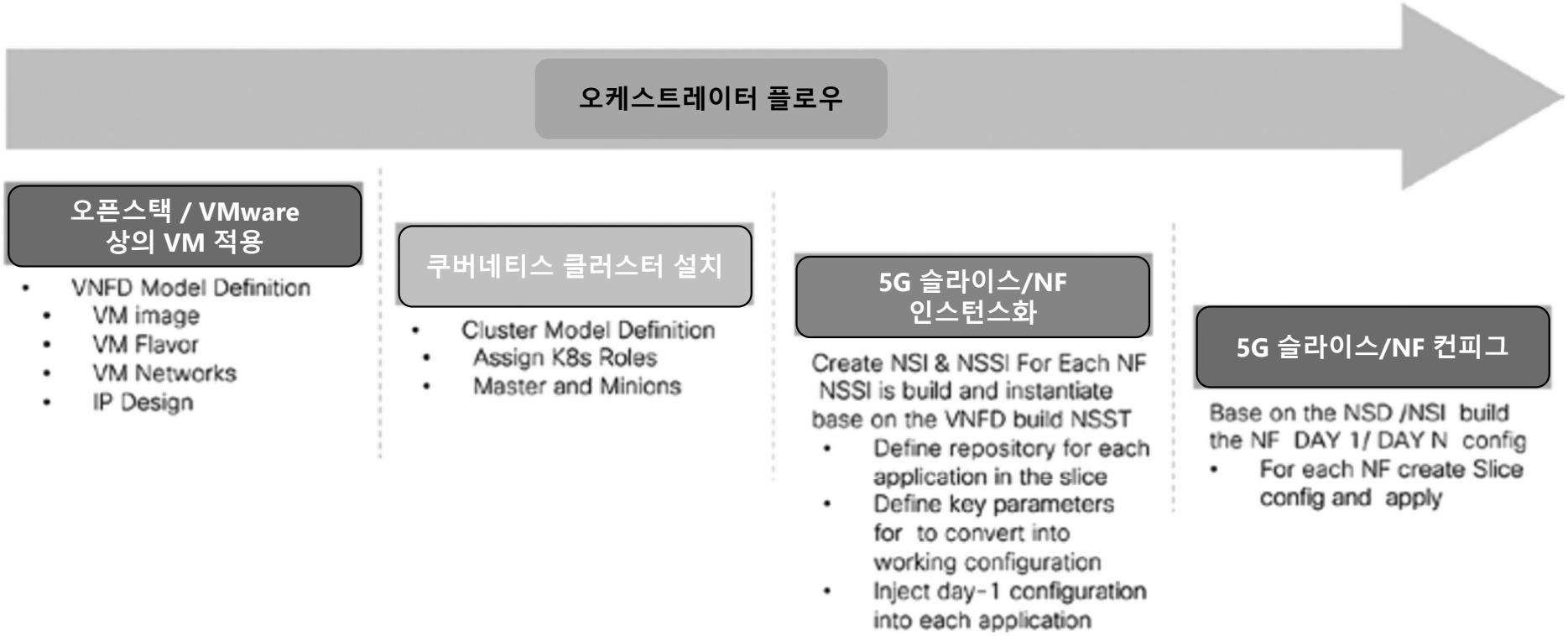
- A set of software networks.
- 네트워크 슬라이싱



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

DAY 2: ENHANCED MOBILE BROADBAND

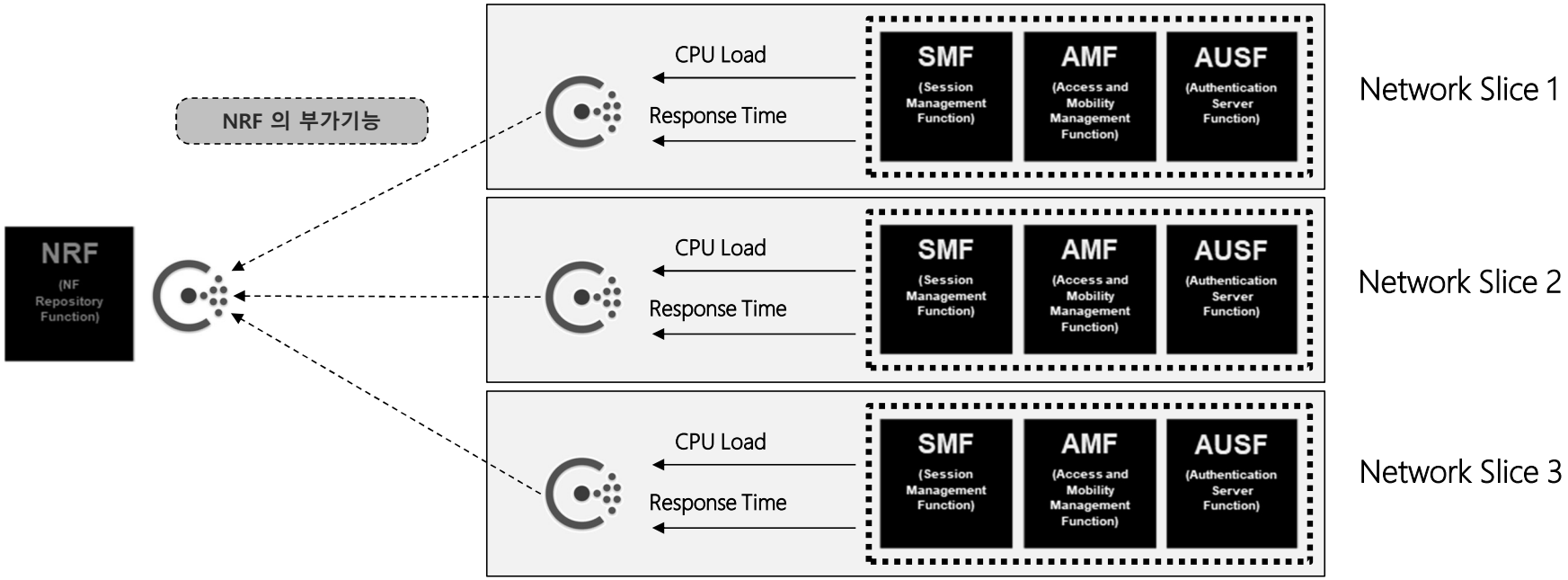
❖ 5G core NF and slice creation



Source: 5G Mobile Core Network, Rajaneesh Sudhakar Shetty, apress

DAY 2: ENHANCED MOBILE BROADBAND

- ❖ Management 부가 기능: Consul Cluster (HashiCorp)
- ❖ Management Trend 고려: Service Mesh (Istio)



DAY 2: ENHANCED MOBILE BROADBAND

❖ 자동화를 위한 소프트웨어 정의 네트워크(SDN) 기술 확장

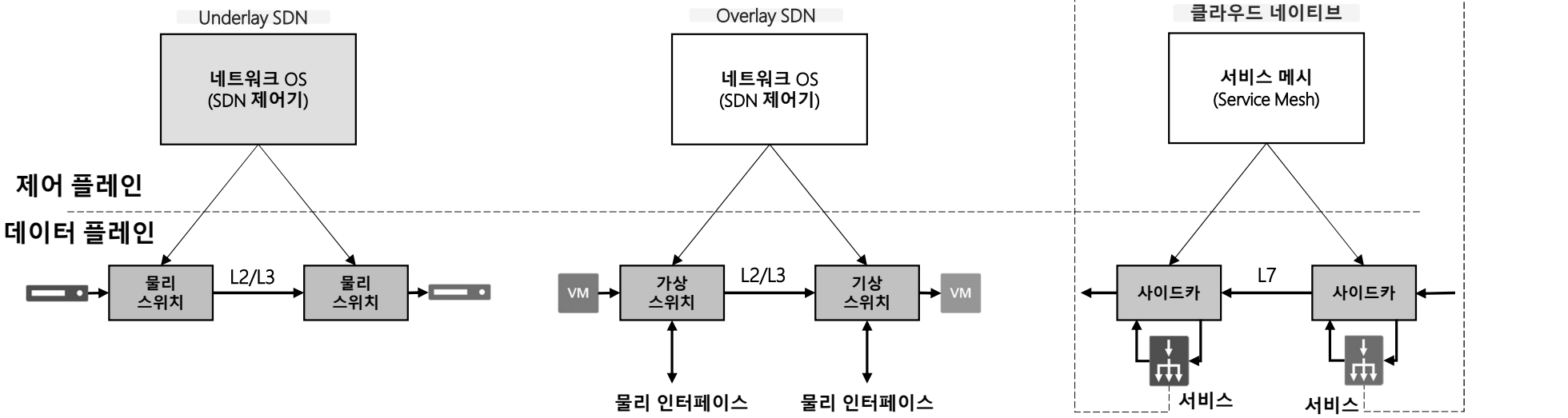
- 언더레이(Underlay) SDN
- 오버레이(Overlay) SDN - 가상화 네트워크
- 서비스 메시(Service Mesh) - 클라우드 네트워크

AMF
(Access and Mobility Management Function)

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: free5gc-amf-deployment
spec:
  selector:
    matchLabels:
      app: free5gc-amf
  replicas: 3
  template:
    metadata:
      labels:
        app: free5gc-amf
```

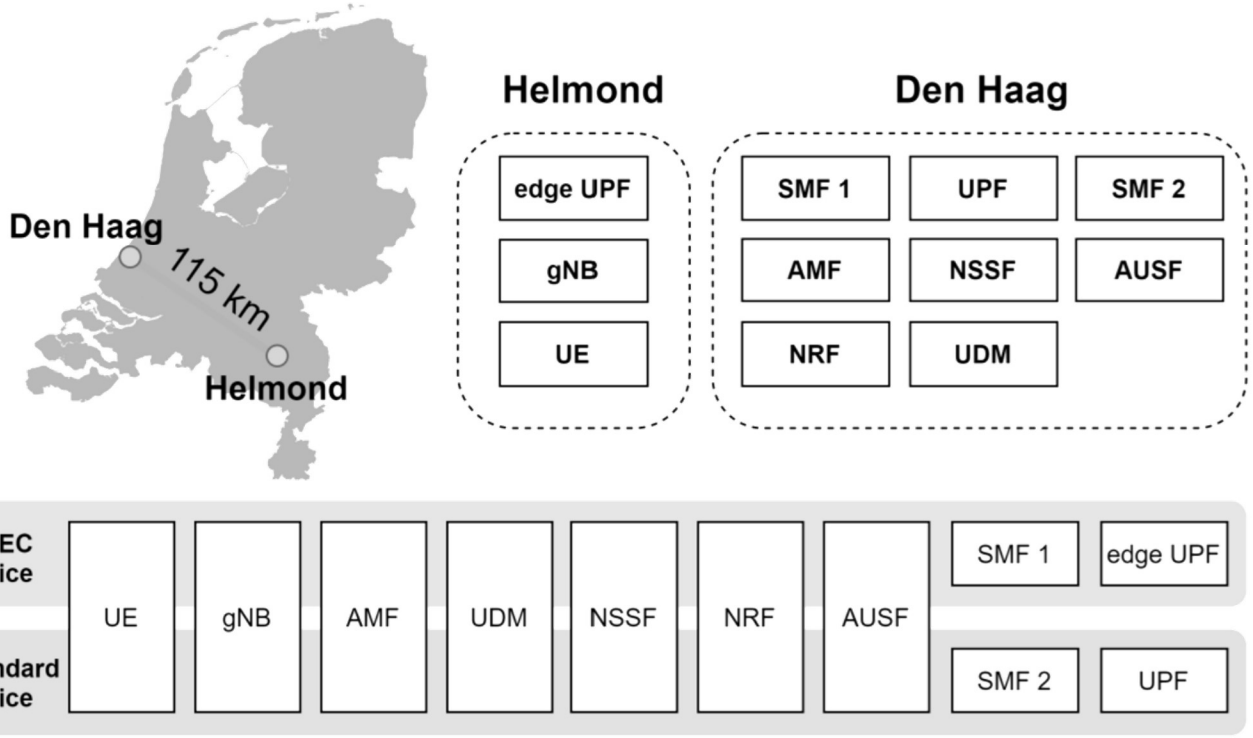
SMF
(Session Management Function)

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: free5gc-smf-deployment
spec:
  selector:
    matchLabels:
      app: free5gc-smf
  replicas: 3
  template:
    metadata:
      labels:
        app: free5gc-smf
```



DAY 2: ENHANCED MOBILE BROADBAND

❖ Configurations of multi-slice UE in 5G SA with MEC

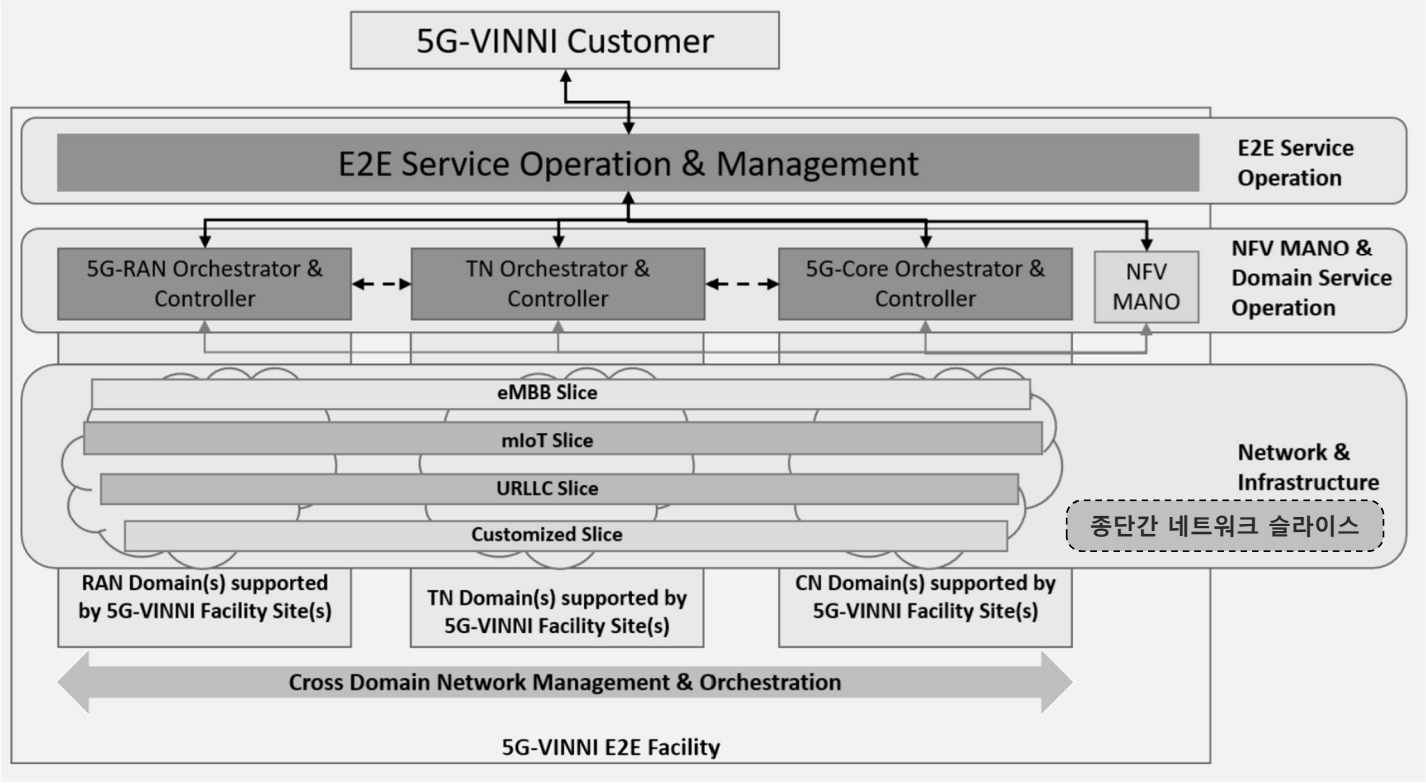


Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

DAY 2: ENHANCED MOBILE BROADBAND

❖ E2E Network Slicing Architecture

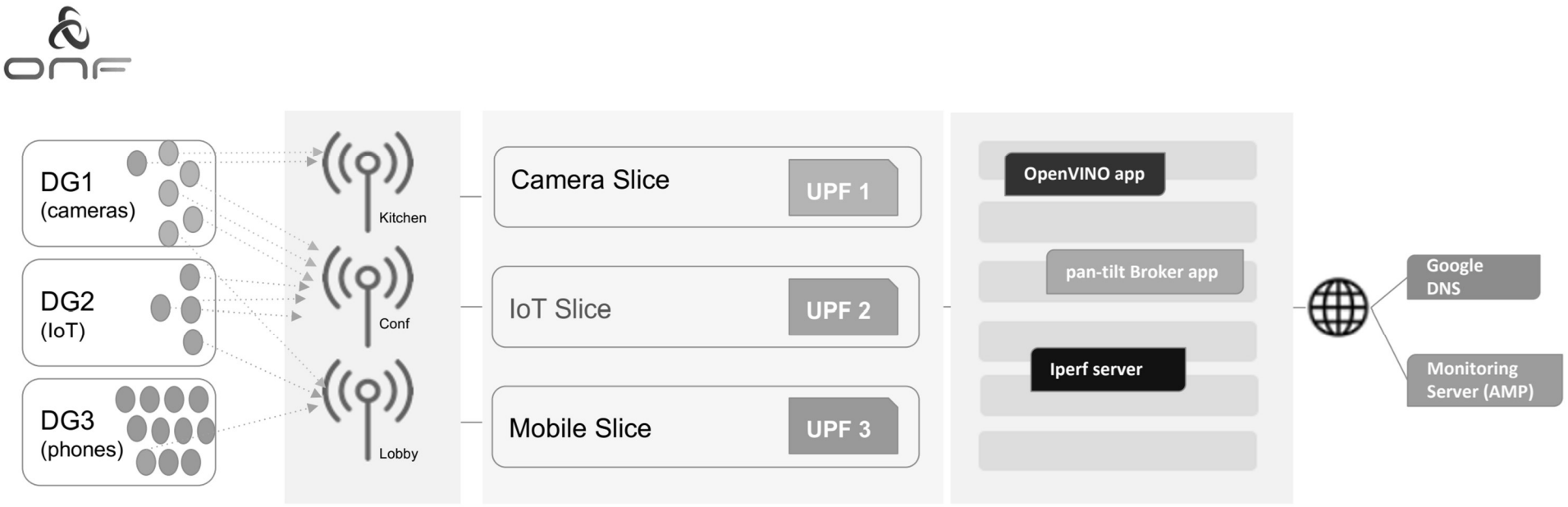
Architectural solution	5G PPP Project
Slice ordering architecture and lifecycle management	5G VINNI
Slice Manager	5GENESIS
Composition and sharing of end-to-end network slices for vertical service arbitration	5Growth



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

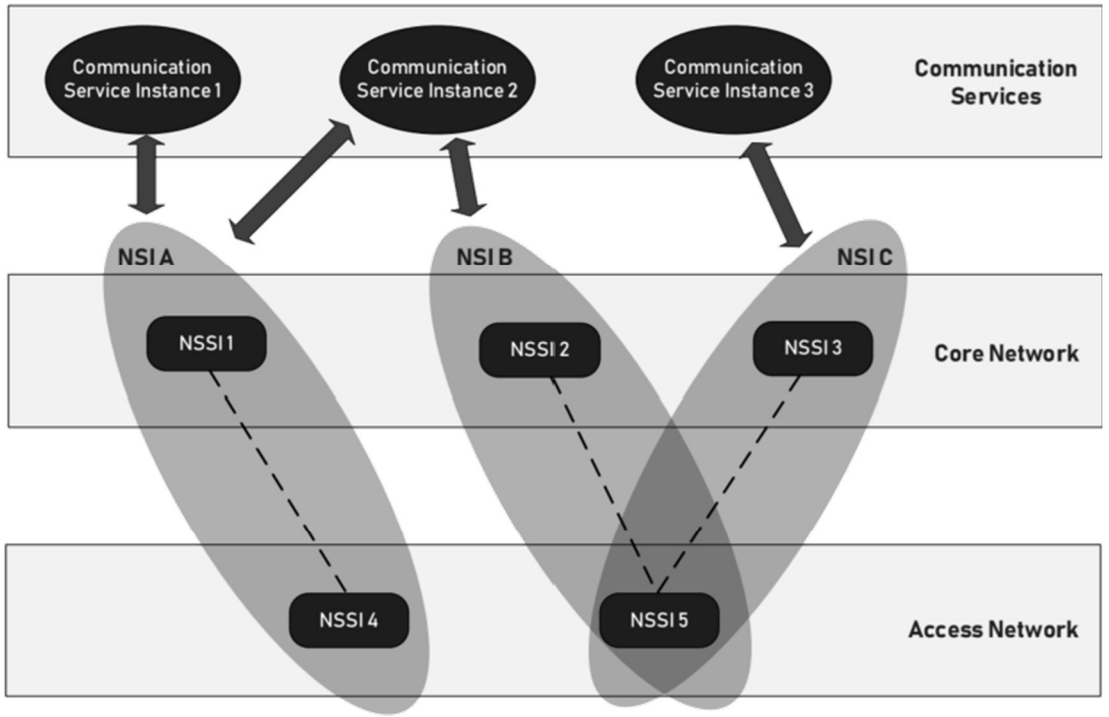
DAY 2: ENHANCED MOBILE BROADBAND

❖ **Sample Enterprise Network**



DAY 2: ENHANCED MOBILE BROADBAND

❖ 3GPP Slicing model



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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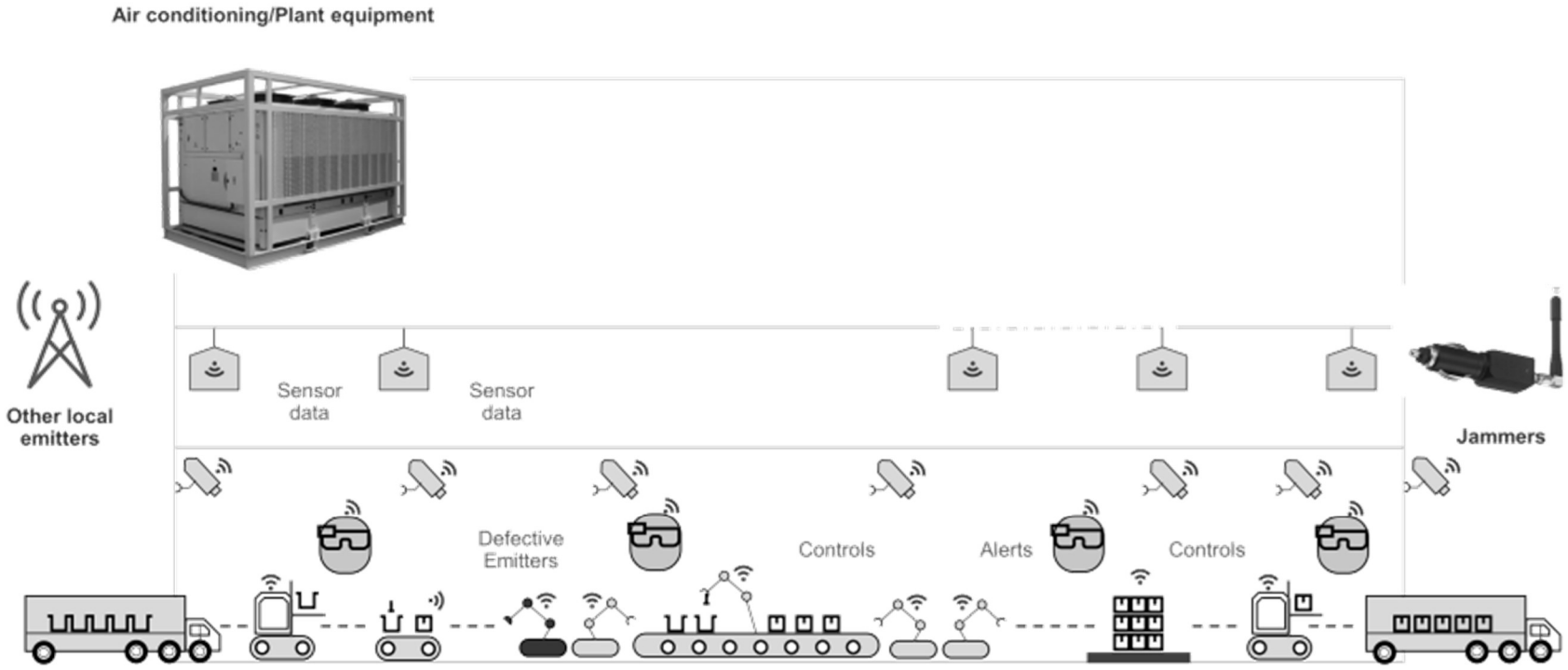
❖ **A typical factory environment blocks and reflects RF signals. Source: Keysight**



Source: https://www.ednasia.com/designing-and-testing-industrial-devices-for-5g-private-networks/

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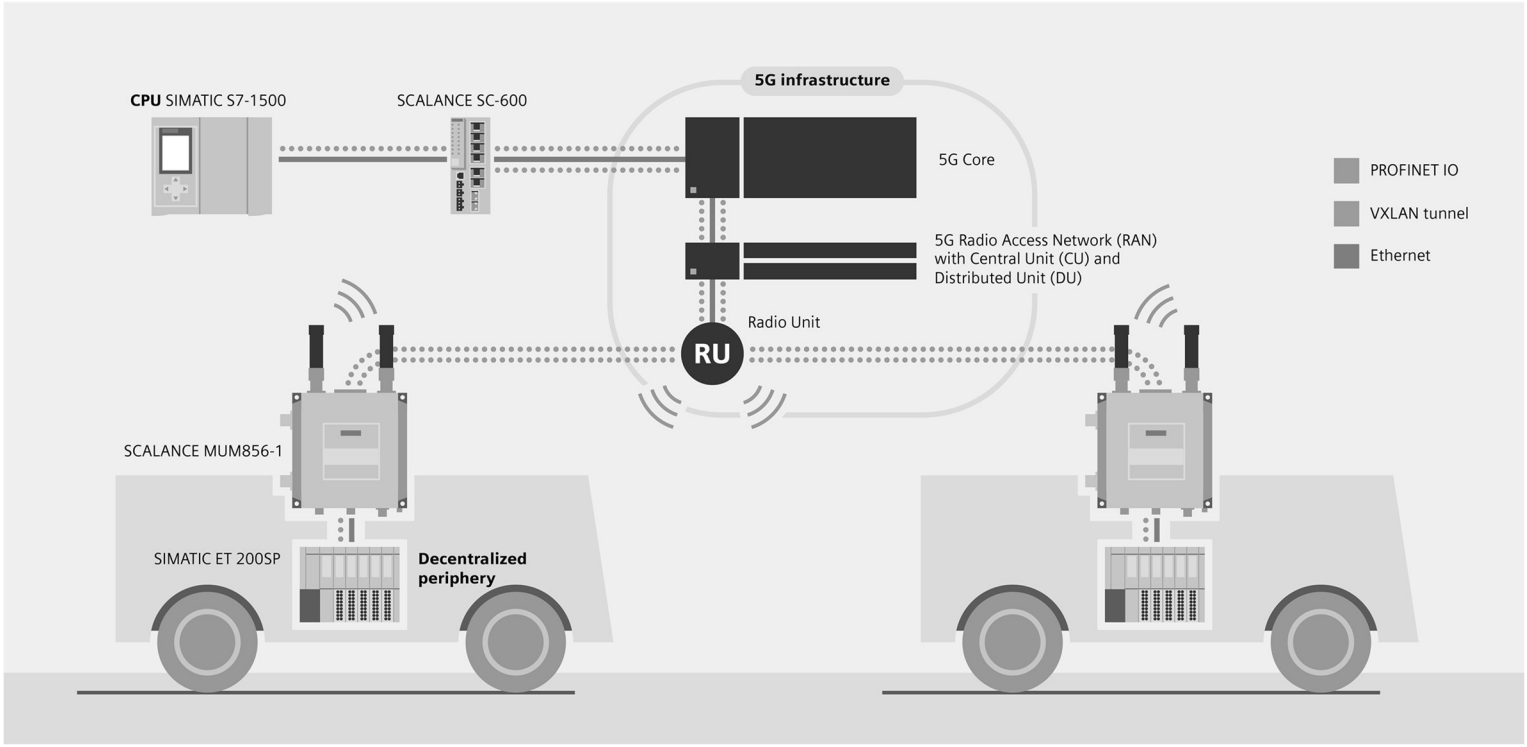
❖ Industrial 5G at the Hannover Messe



Source: https://press.siemens.com/global/en/pressrelease/real-time-communication-5g-profinet

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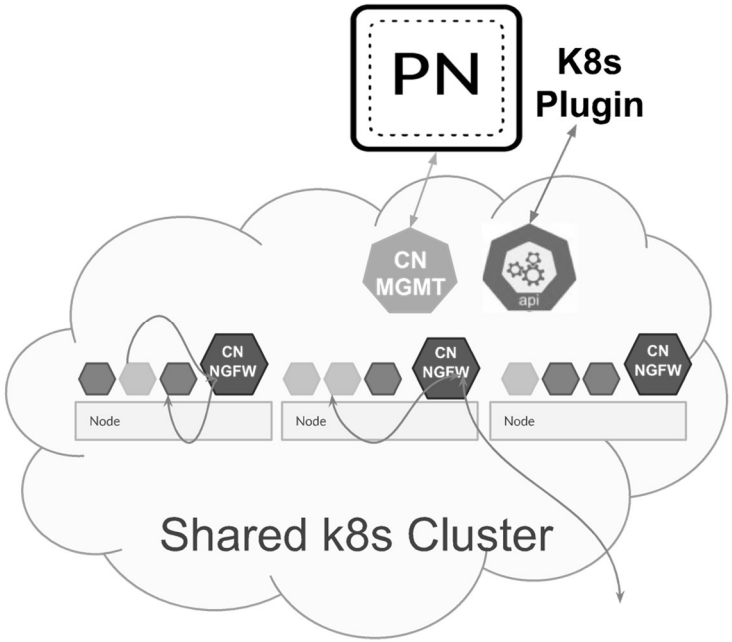
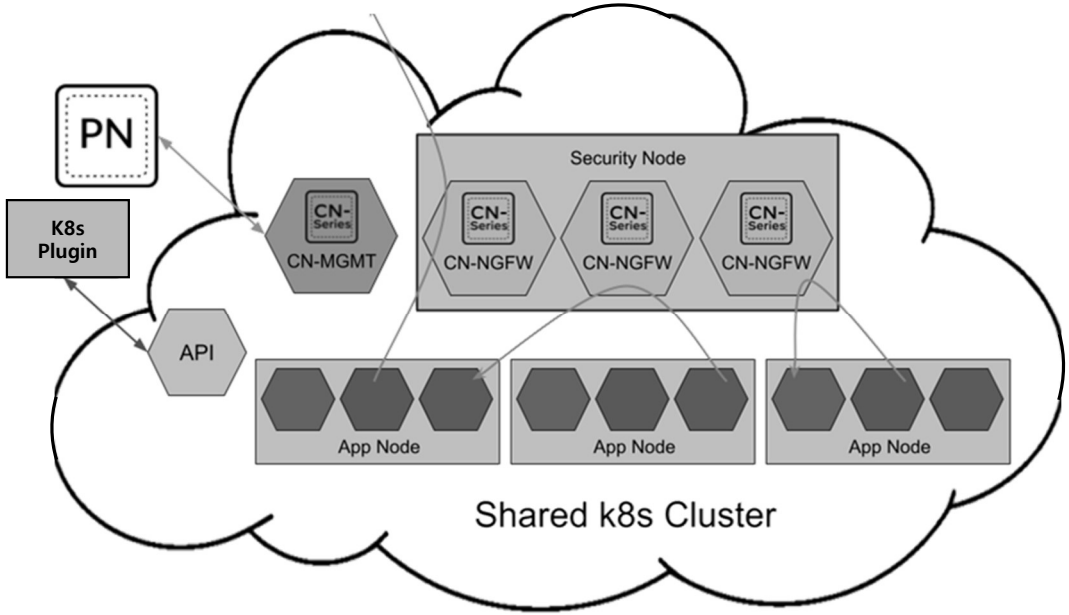
❖ Private 5G

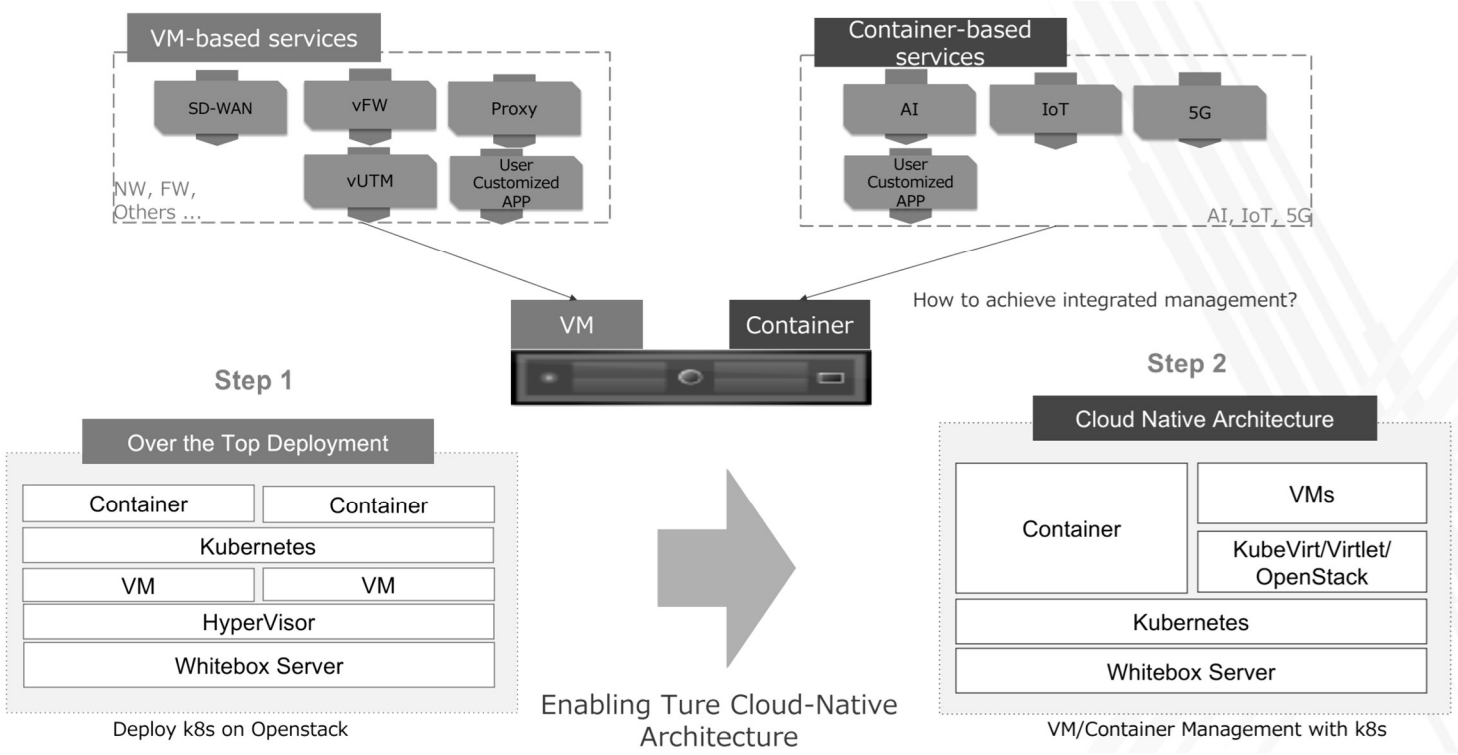
- PAN-CNI plugin for network insertion





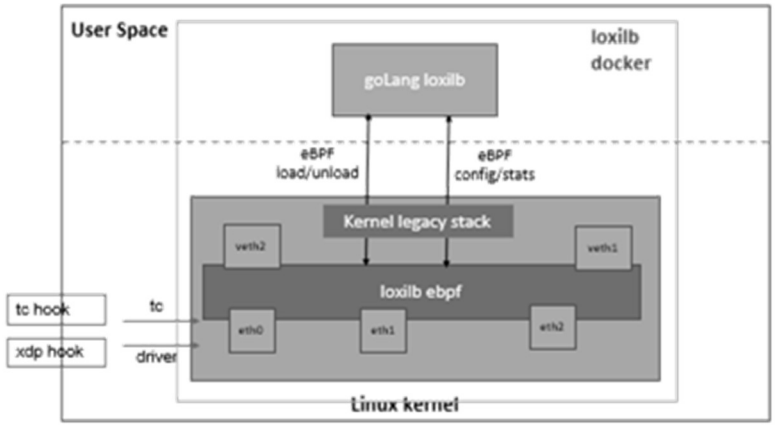
DAY 2: ENHANCED MOBILE BROADBAND

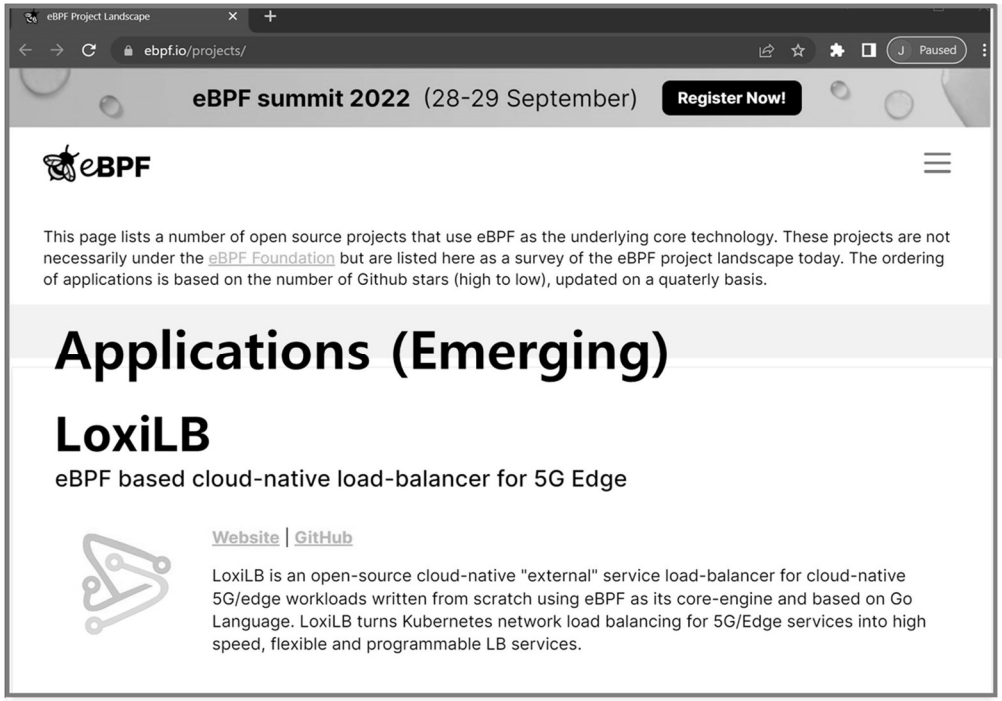
❖ NFV (Network Functions Virtualization) and beyond



❖ Cloud Native LB for 5G Edge (예): LoxiLB

- LB
- goBGP
- SRv6
- SCTP
- GTP



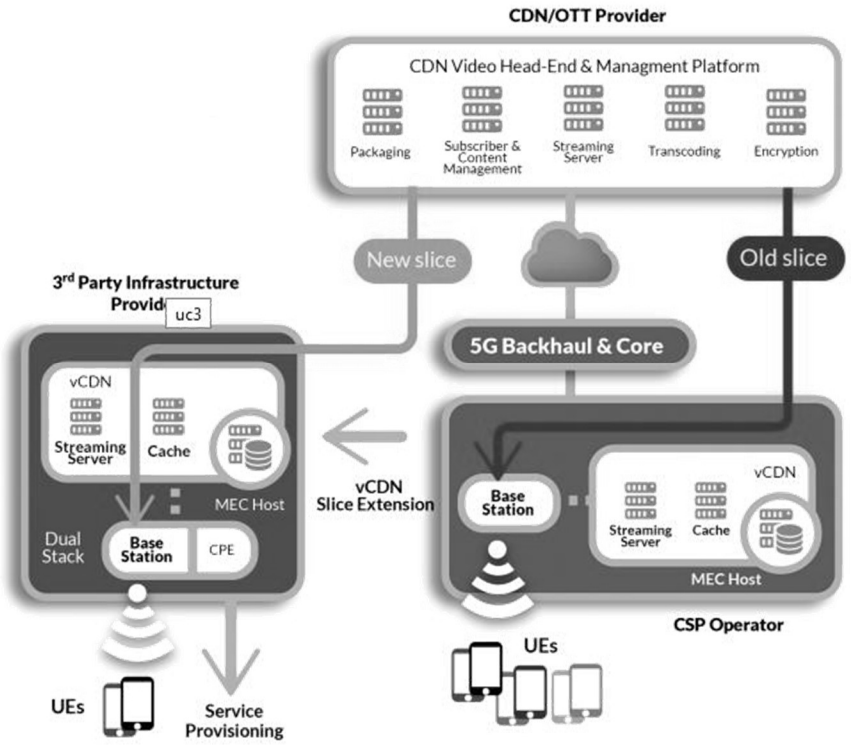


Source: https://ebpf.io/projects/

DAY 2: ENHANCED MOBILE BROADBAND

❖ vCDN use-case with elastic MEC-enabled slices

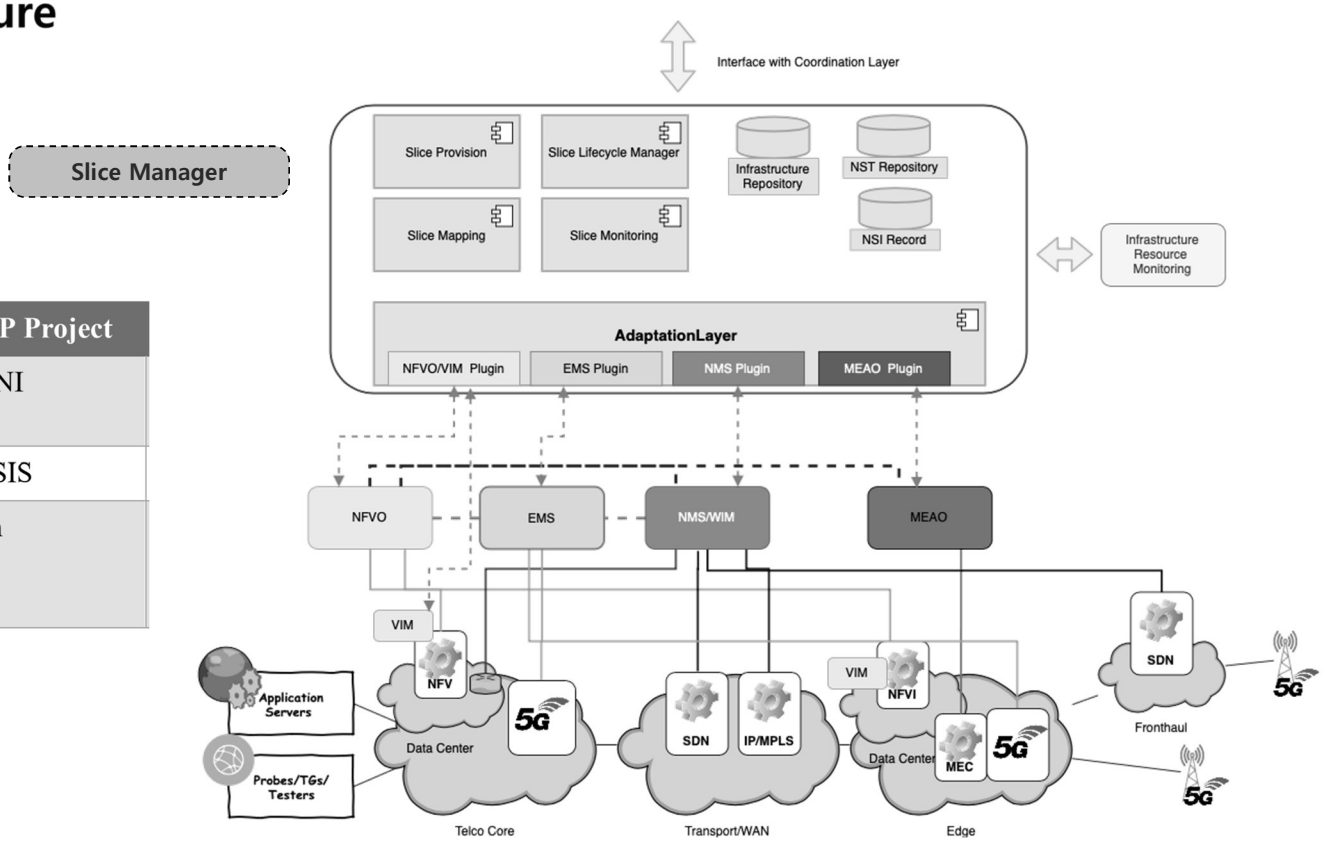
vCDN의 스케일아웃 확장



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

❖ Slice Manager Architecture

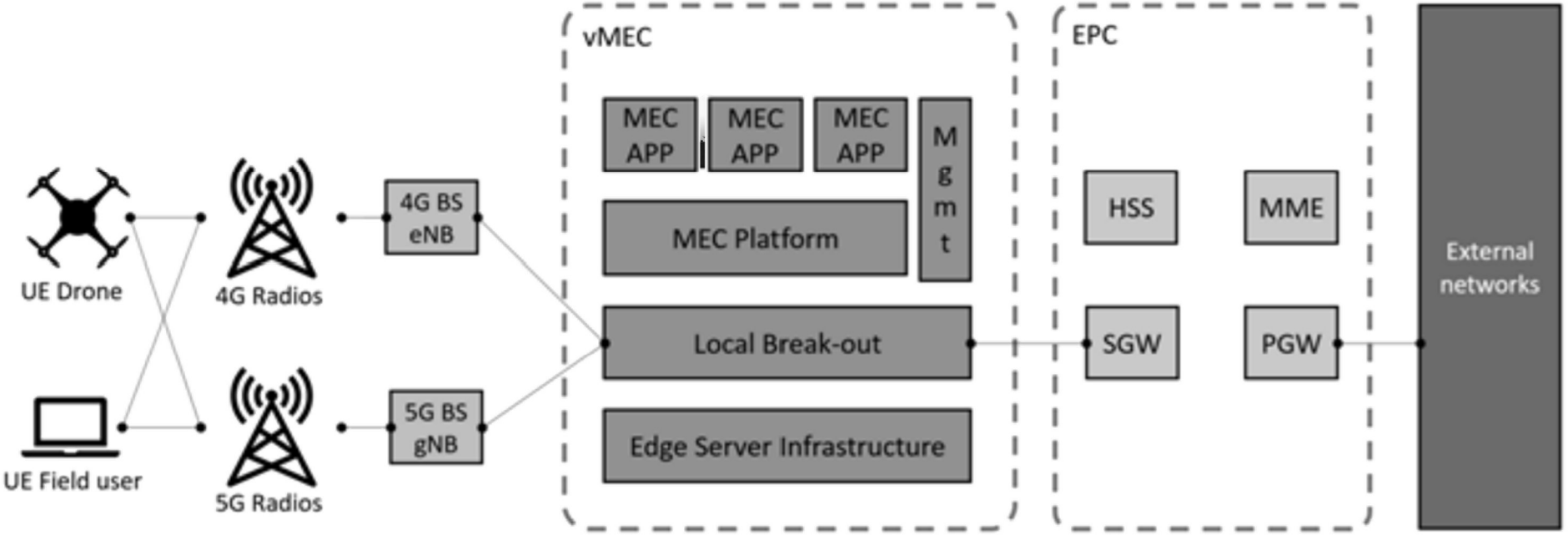
Architectural solution	5G PPP Project
Slice ordering architecture and lifecycle management	5G VINNI
Slice Manager	5GENESIS
Composition and sharing of end-to-end network slices for vertical service arbitration	5Growth



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

DAY 2: ENHANCED MOBILE BROADBAND

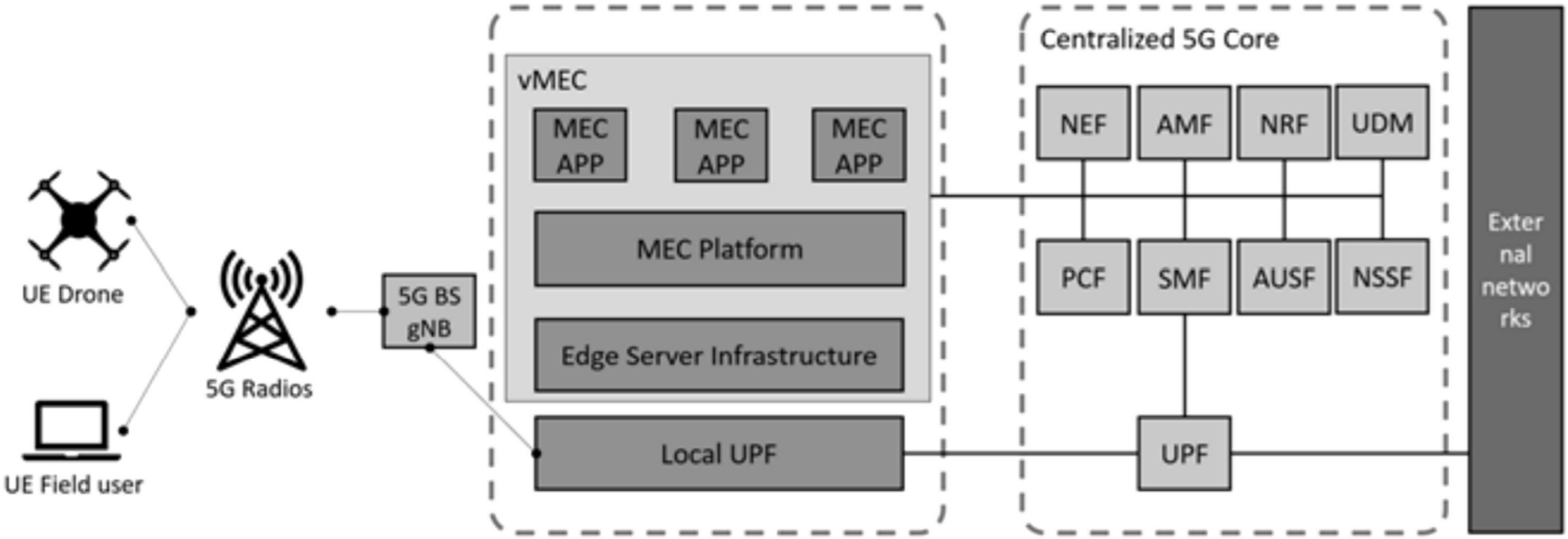
❖ **5GTN MEC deployment in NSA mode**



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

DAY 2: ENHANCED MOBILE BROADBAND

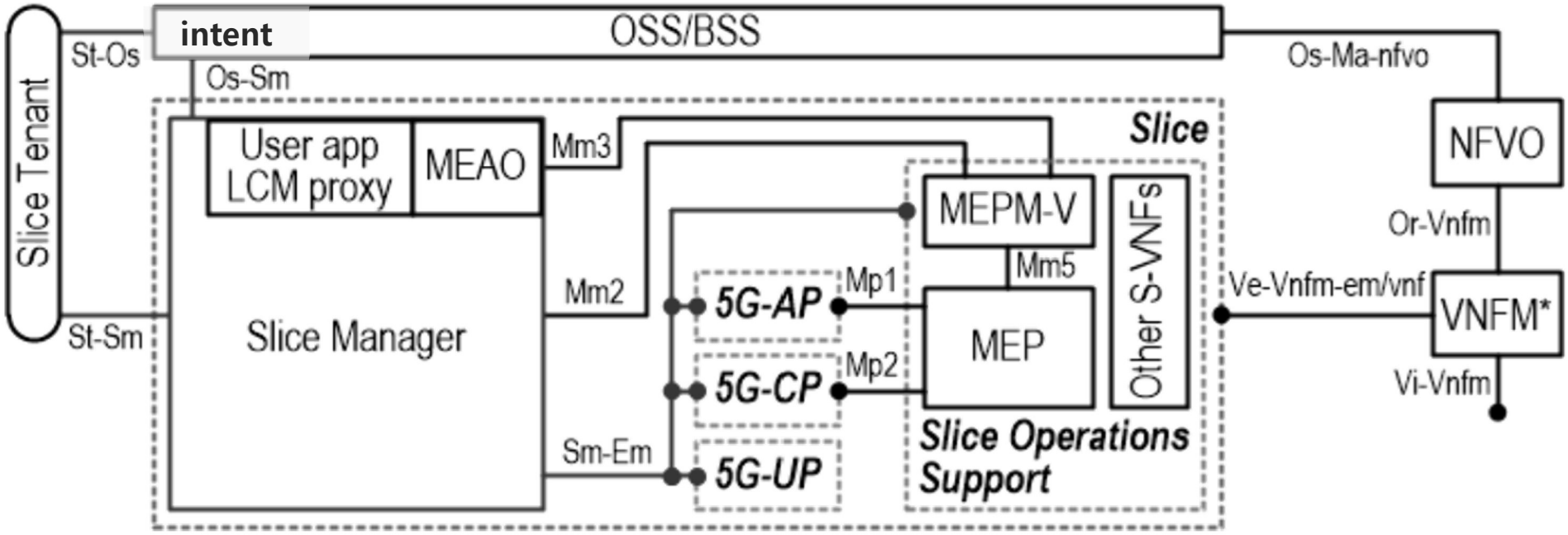
❖ 5GTN MEC deployment in SA mode



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

DAY 2: ENHANCED MOBILE BROADBAND

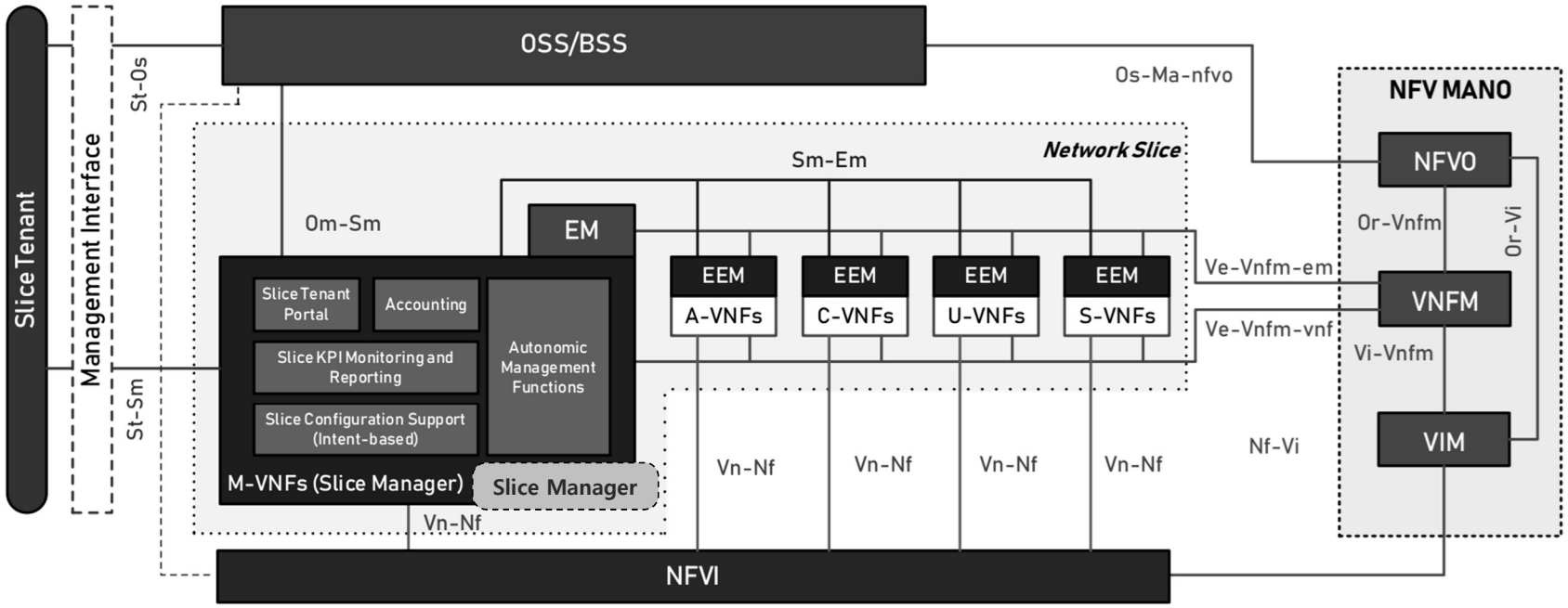
❖ **MEC-enabled intent-based management architecture**



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

DAY 2: ENHANCED MOBILE BROADBAND

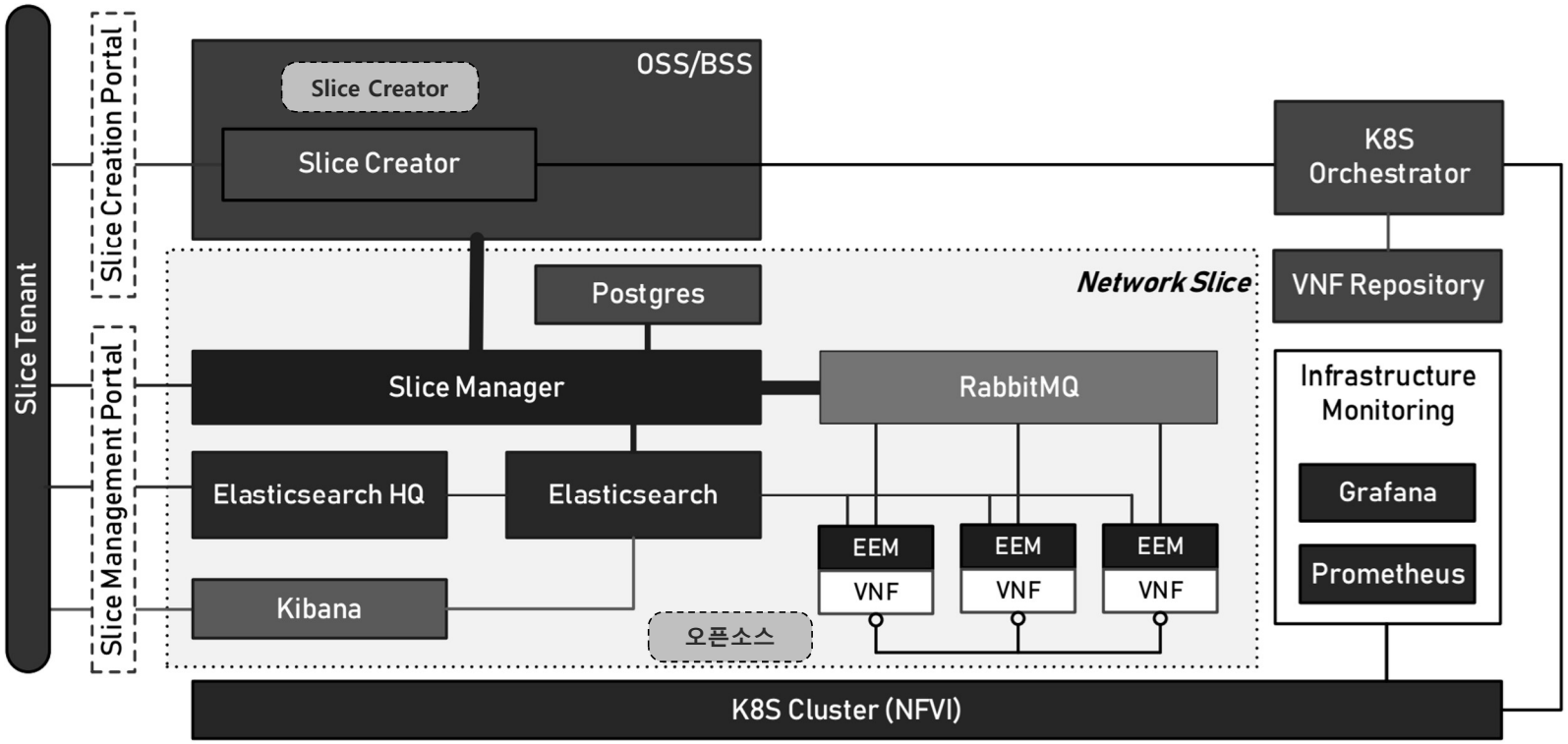
❖ **Intent-based management framework with the internal structure of network slices – ETSI NFV MANO extensions (slice management plane shown in navy blue)**



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

DAY 2: ENHANCED MOBILE BROADBAND

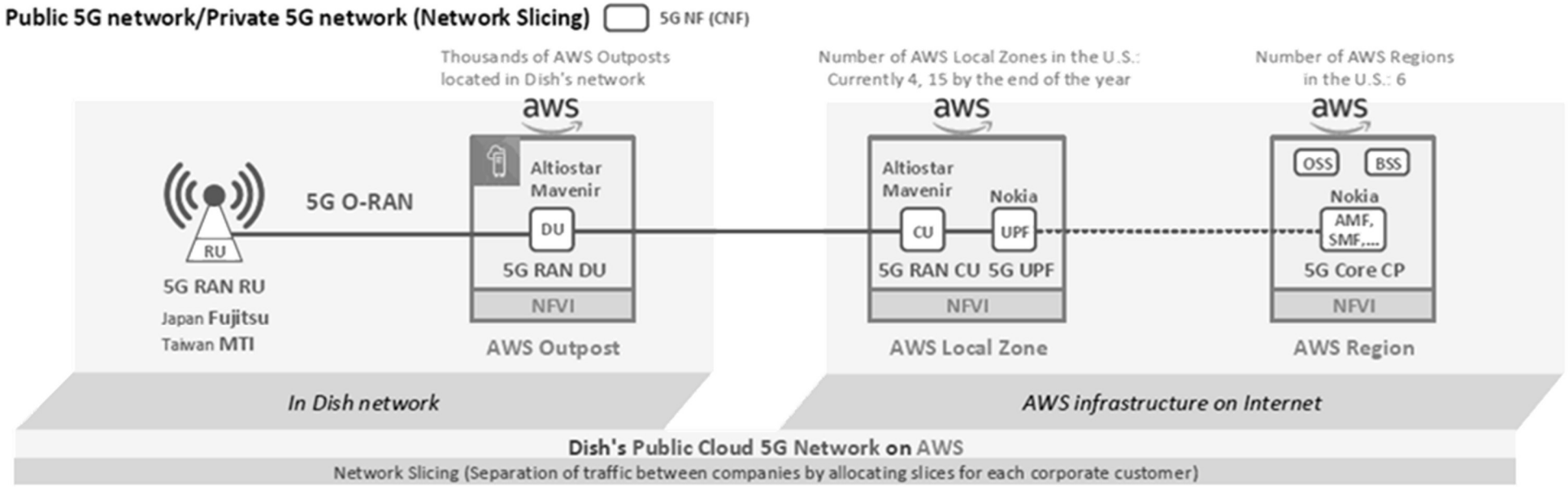
❖ **Exemplary implementation of ISM utilizing K8s as the VNF orchestrator**



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

❖ 네트워크 슬라이싱

- **Public 5G 네트워크 / Private 5G 네트워크**



Source: Netmanias

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G 클라우드화 아키텍처

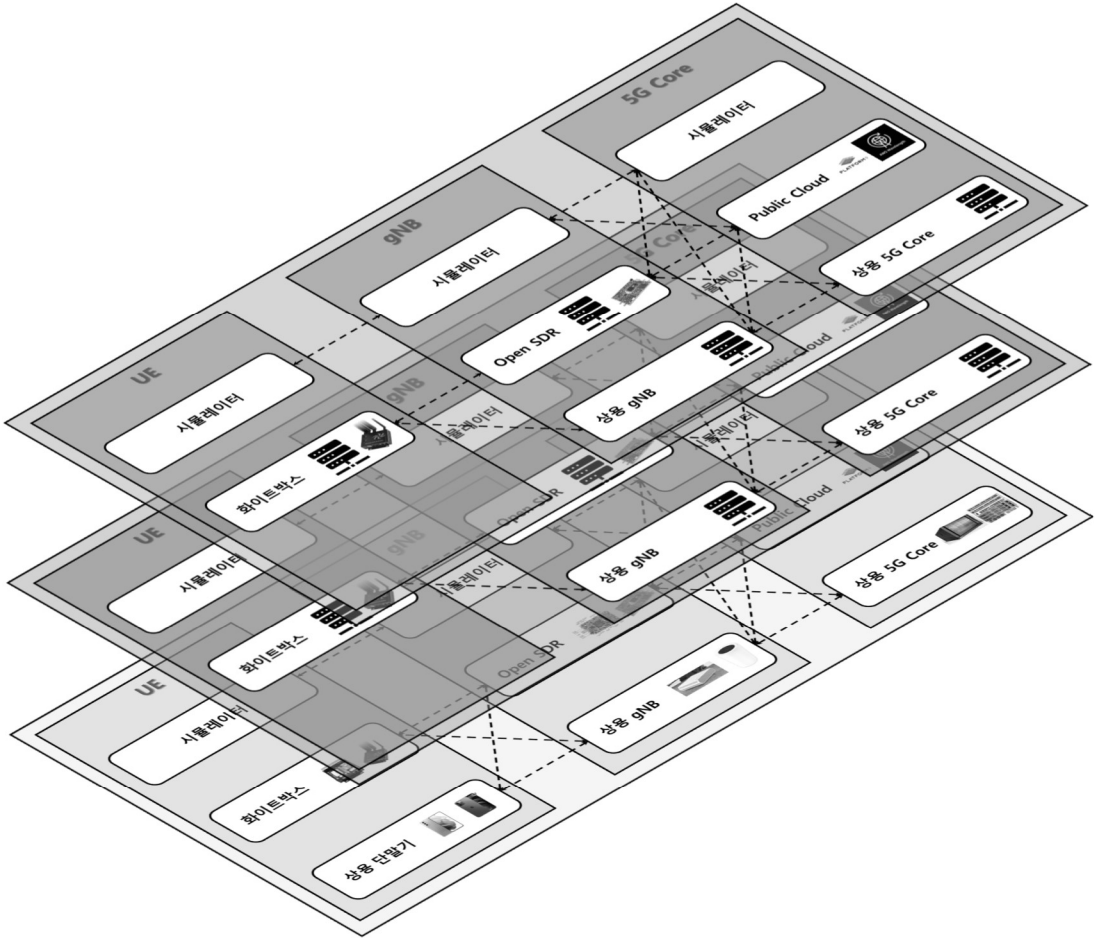
- 물리 계층
- 가상화 계층
- 클라우드화 계층

네트워크 보안	• 모든 네트워크 기능을 포함하는 보안 (물리, 가상, 컨테이너)
애플리케이션 보안	• 5G 네트워크 상에 동작하는 서비스와 애플리케이션의 보안
물리적 보안	• 하드웨어, 셀 사이트, PoP 보안

클라우드 계층

가상 계층

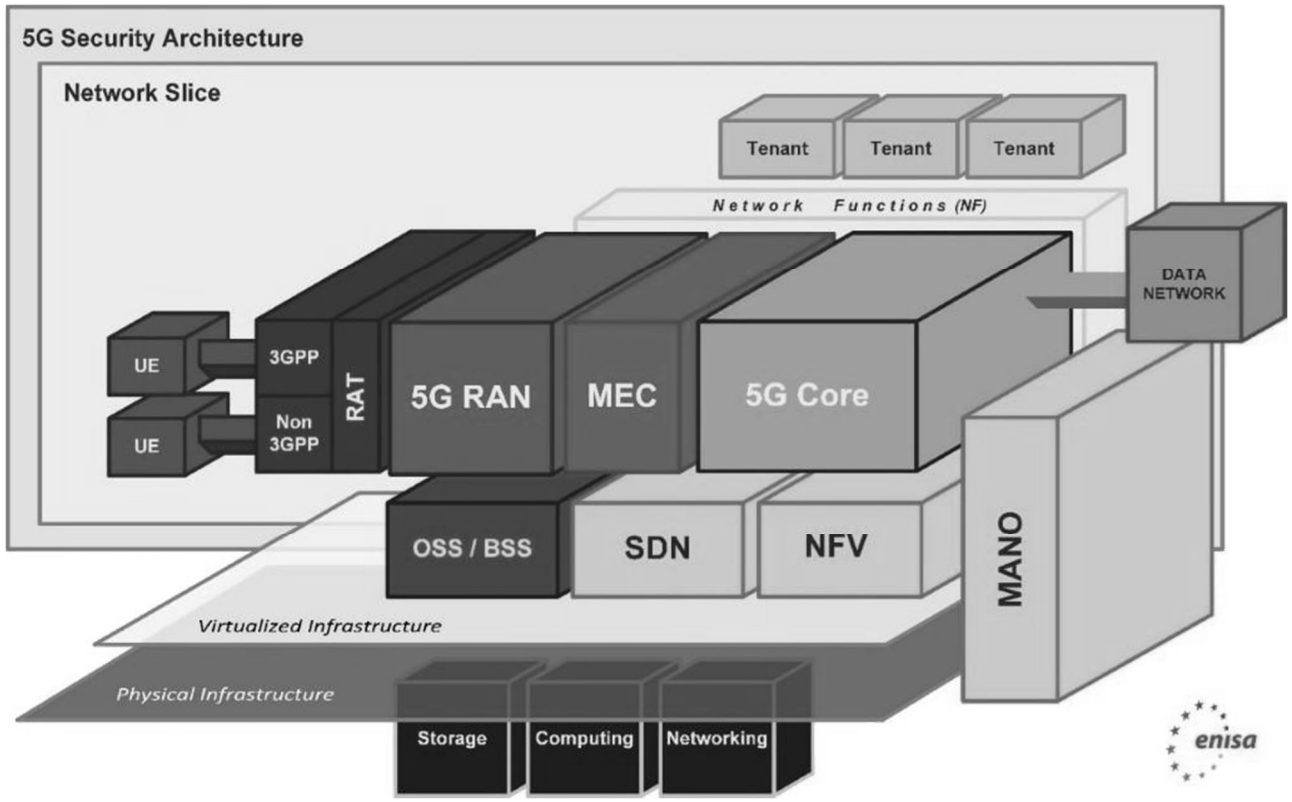
물리 계층



DAY 2: ENHANCED MOBILE BROADBAND

❖ 네트워크 슬라이싱 (예): **ENISA**(European Union Agency for Cybersecurity)

슬라이스별 5G 보안 아키텍처

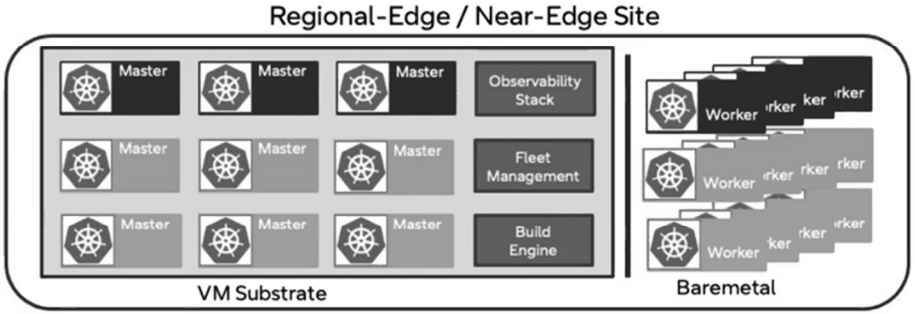


Source: ENISA 5G Security Architecture

DAY 2: ENHANCED MOBILE BROADBAND

❖ Edge Pattern for Infra

- **Multi-Cluster**
- **Standalone**

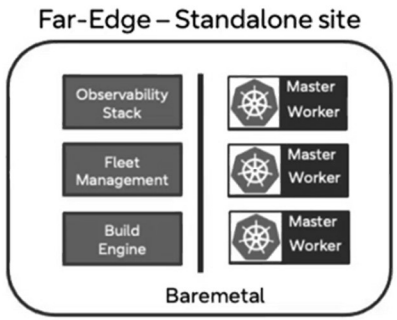


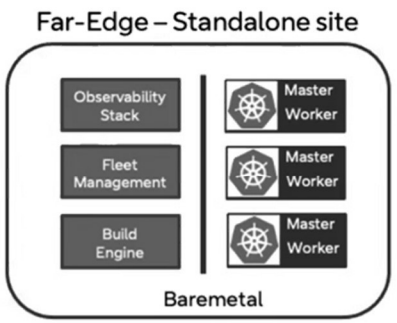
1. High Security Multi-Cluster

- Regional or Near-edge site supporting multiple racks of compute
- Multi-cluster, for different function types e.g. RAN 'vs' AR/VR Cache
- VMs provide security and efficiency for hosting K8s-masters and supporting functions, in a multi-cluster environment

2. Standalone

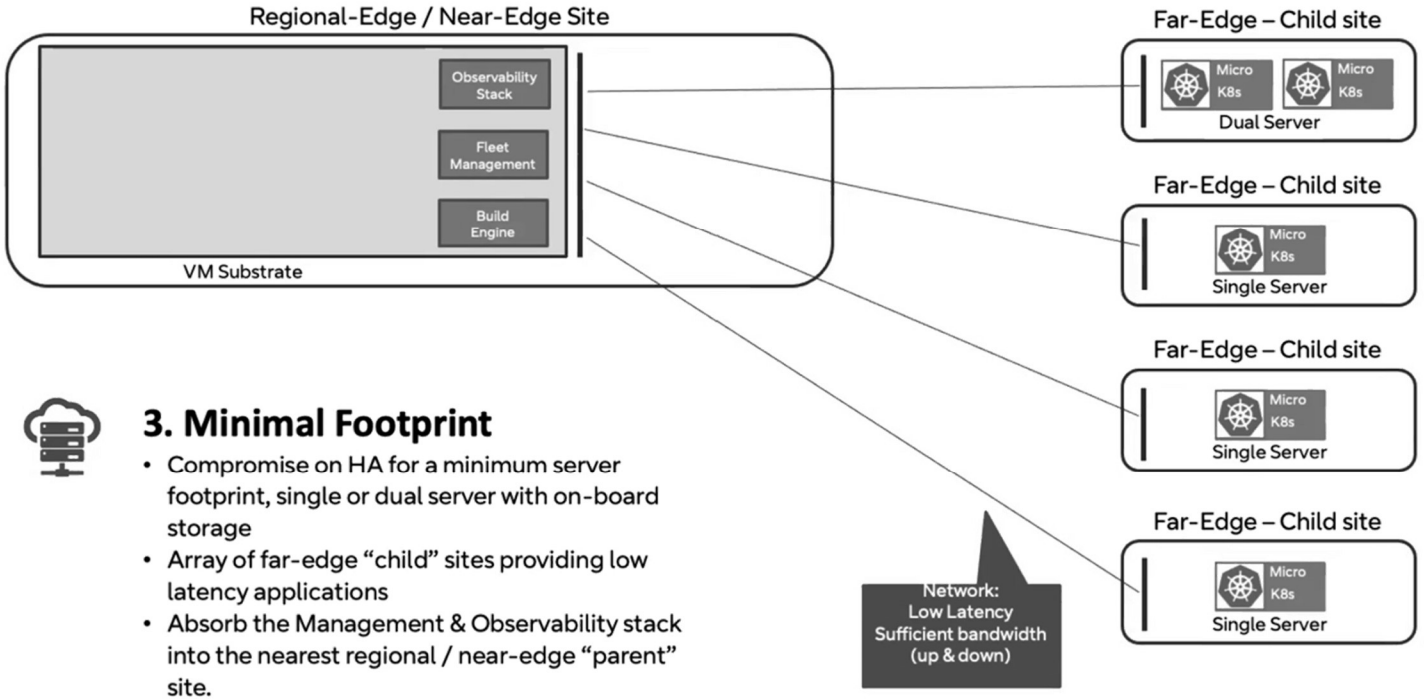
- Low Compute e.g. Single Racks, with local or software-defined storage
- Lower Latency / High Performance Edge
- Standalone, dedicated applications, with HA and supporting mgmt. functions e.g. Private Network Edge





❖ Edge Pattern for Infra

- **Minimal Footprint**

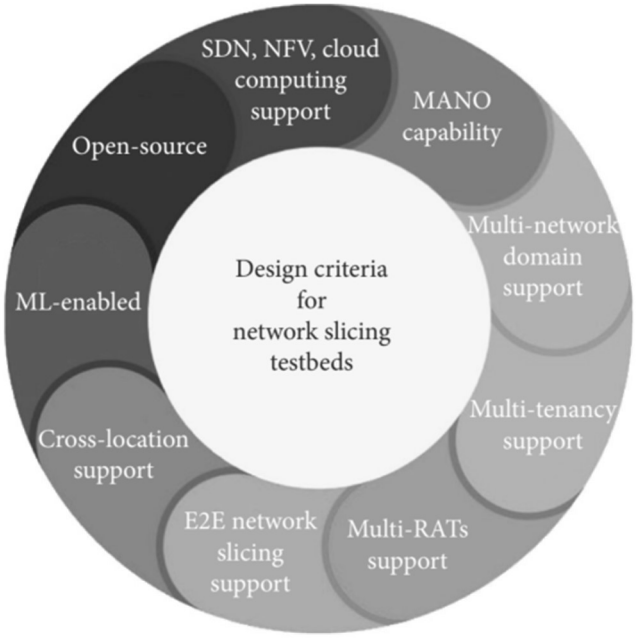


3. Minimal Footprint

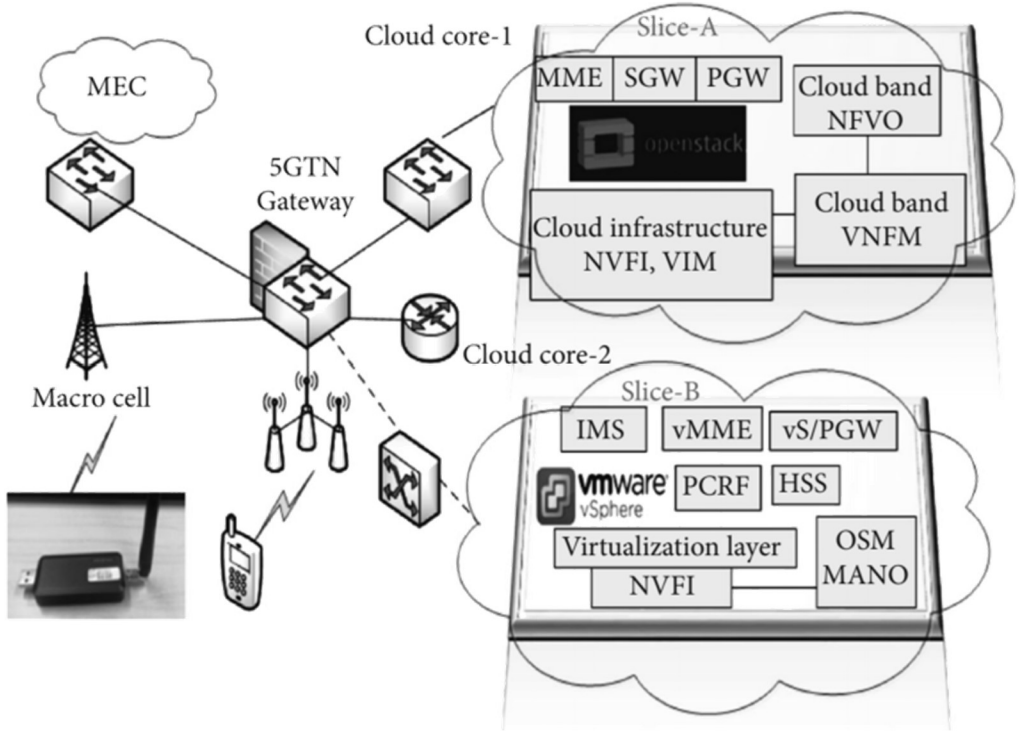
- Compromise on HA for a minimum server footprint, single or dual server with on-board storage
- Array of far-edge "child" sites providing low latency applications
- Absorb the Management & Observability stack into the nearest regional / near-edge "parent" site.

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5GTN testbed architecture (OpenStack / VMware)



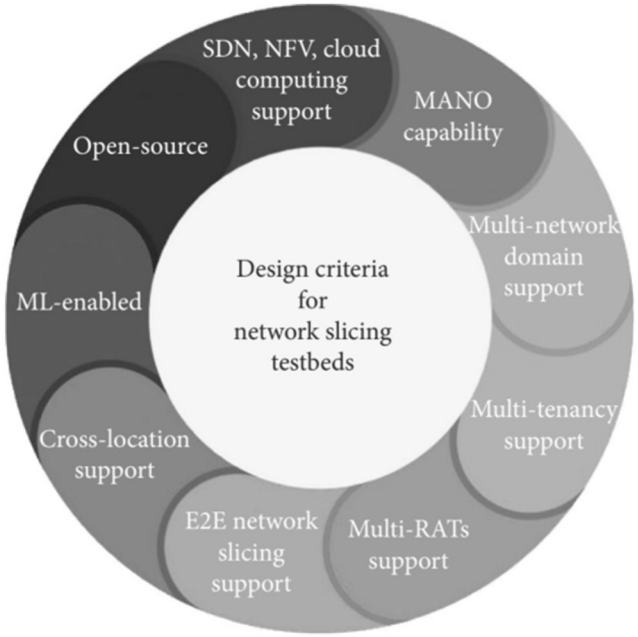
Design criteria for network slicing testbeds.



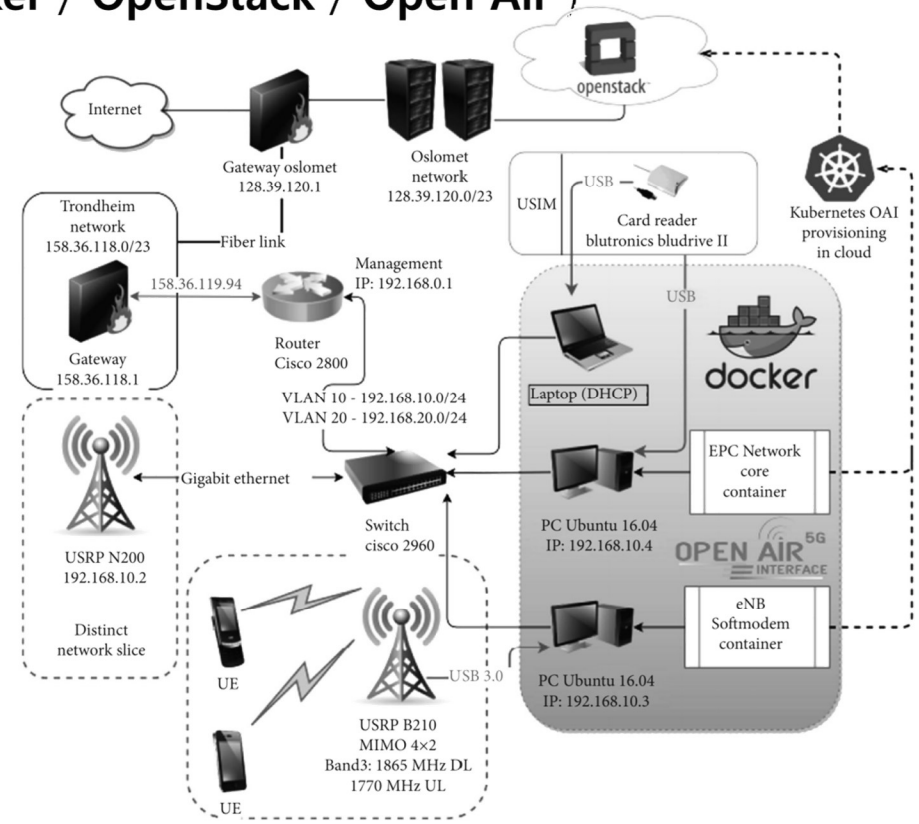
Source: Wireless Communications and Mobile Computing, Volume 2021, Article ID 6655216, 26 pages, https://doi.org/10.1155/2021/6655216

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G for IoT testbed architecture (K8s / Docker / OpenStack / Open Air)



Design criteria for network slicing testbeds.



Source: Wireless Communications and Mobile Computing, Volume 2021, Article ID 6655216, 26 pages, https://doi.org/10.1155/2021/6655216

DAY 2: ENHANCED MOBILE BROADBAND

❖ **Comparison of small-scale testbeds for network slicing in 5G,**

- **denotes supported feature**
- **denotes unsupported feature**

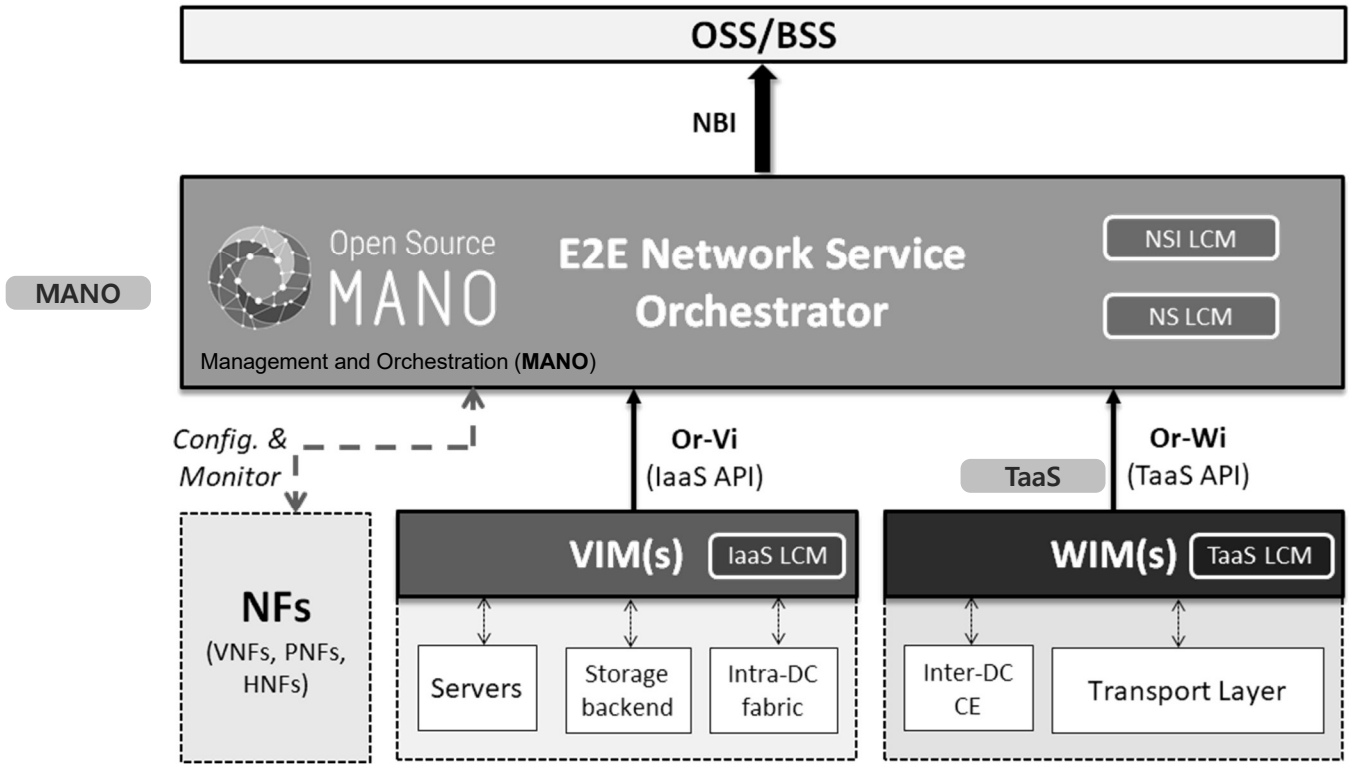
Testbed	SDN	NFV	Cloud comp.	Multi-domain	Multi-tenancy	MANO	Multi-RATs	E2E slicing	Cross-location	ML-enabled	Open-source	MANO type
1. 5G4IoT [38, 39]	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
2. 5GTN [40]	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✓ (https://5gtn.fi/)	OSM, CloudBand
3. SEMIoTICS [41]	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓ (https://www.semiotics-project.eu/)	OpenStack tacker
4. Mosaic5G [43]	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓ (http://mosaic5g.io/)	JOX
5. Orion [45, 46]	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✗	OSM and a customized orchestrator
6. 5G Testbed for NS [47]	✗	✓	✓	✓	✗	✗	✗	✓	✗	✗	✓ (https://github.com/ashxz47)	✗
7. POSENS [48, 49]	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓ (https://github.com/wnlUc3m)	Customized OSM
8. UPC testbed [50]	✓	✓	✗	✓	✓	✗	✓	✗	✗	✓	✗	✗
9. M-CORD based testbed [52, 53]	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓ (https://nick133371.github.io/)	XOS
10. NS for 5G IoT and eMBB [55]	✓	✓	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗
11. Transformable resources slicing testbed [56]	✓	✓	✓	✗(E2E slice traverses over RAN, TN and CN.)	✓	✓	✗	✗	✗	✗	✗	VLSP, Kubernetes, and OpenStack
12. DSAF [58]	✗	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	Customized python-based orchestrator
13. SliceNet [59]	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	OSM, OpenBaton
14. IqInf testbed [60]	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗
15. Slice-aware SA testbed [61]	✓	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	Service assurance integrated with MANO
16. Simula [62, 63]	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓ (https://github.com/simula/5gvinni-oai-ns)	OSM
17. 5GIIK [64, 65]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ (https://bit.ly/3rgOgd6)	OSM
18. ONAP based testbed [67]	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	ONAP
19. BlueArch [68]	✓	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗	Open MANO, RIFT.io
20. MEC IoT platform [69, 70]	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	OSM
21. CAI [71]	✓	✓	✓	✓	✗	✗	✓	✗	✗	✓	✓ (https://bit.ly/3tXErSX)	✗

ONAP

Source: Wireless Communications and Mobile Computing, Volume 2021, Article ID 6655216, 26 pages, https://doi.org/10.1155/2021/6655216

DAY 2: ENHANCED MOBILE BROADBAND

❖ **OSM service platform architecture.**

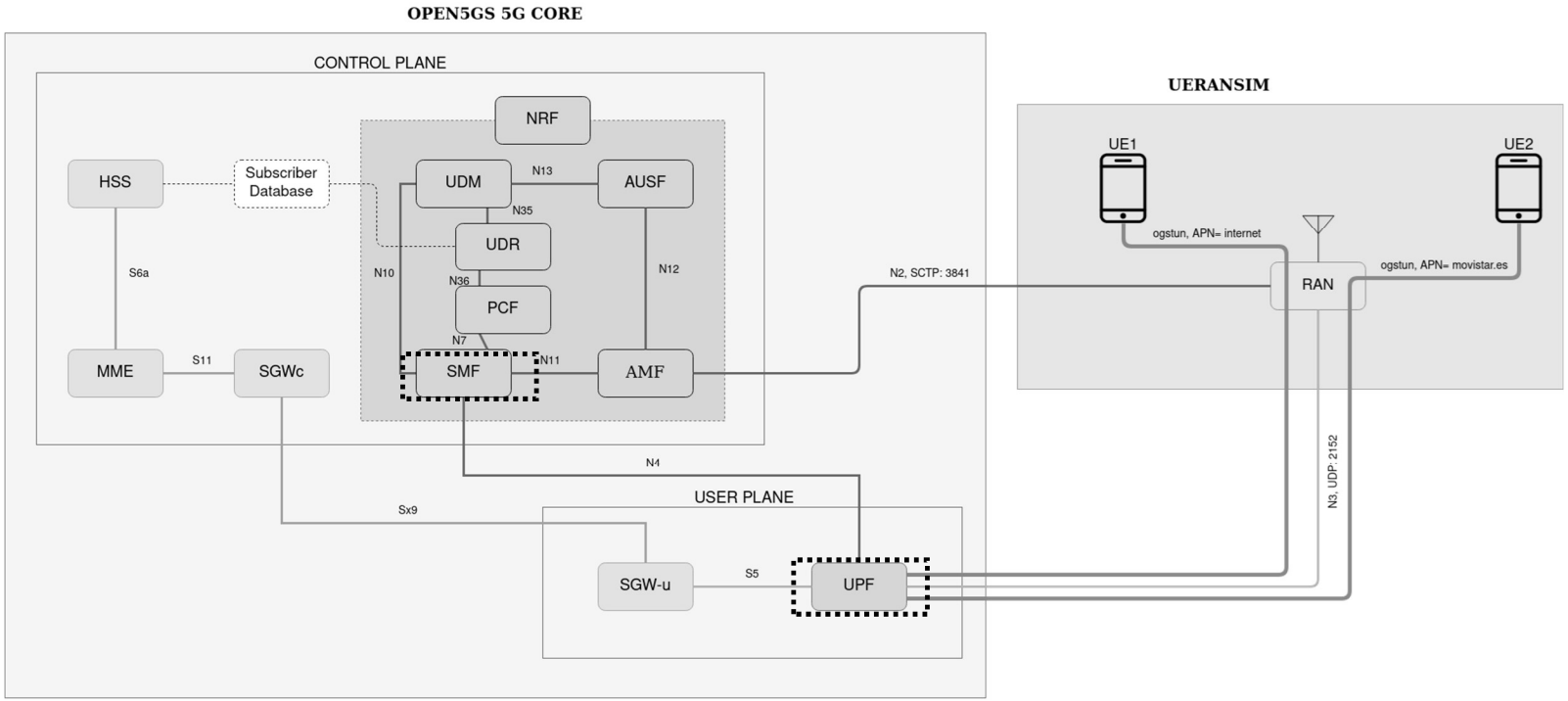


Source: VIRTUALIZED CELLULAR NETWOKS WITH NATIVE CLOUD FUNCTIONS, Iria Míguez González

DAY 2: ENHANCED MOBILE BROADBAND

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

- **Architecture of the Network for the test**

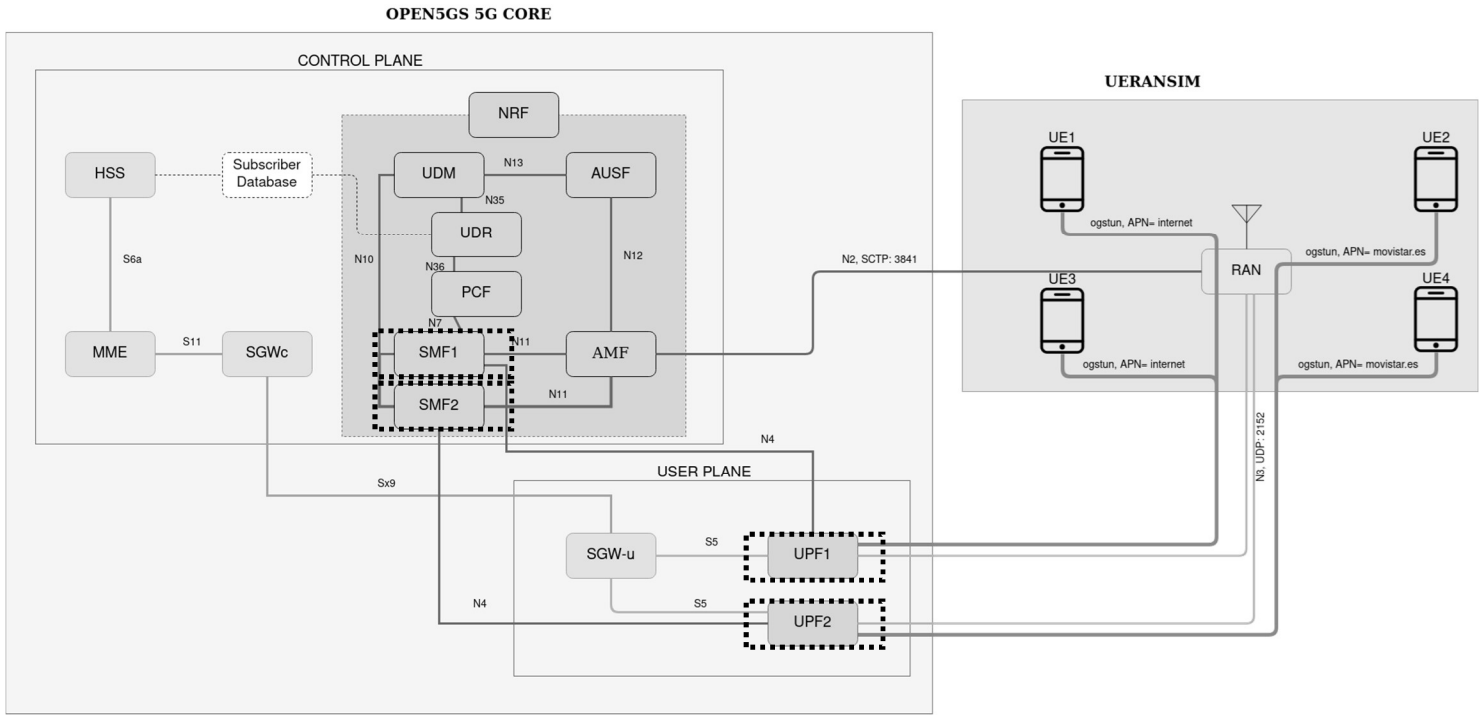


Source: VIRTUALIZED CELLULAR NETWOKS WITH NATIVE CLOUD FUNCTIONS, Iria Míguez González

DAY 2: ENHANCED MOBILE BROADBAND

❖ Selection of UPF and SMF by slice

- iperf Slicing Test Architecture

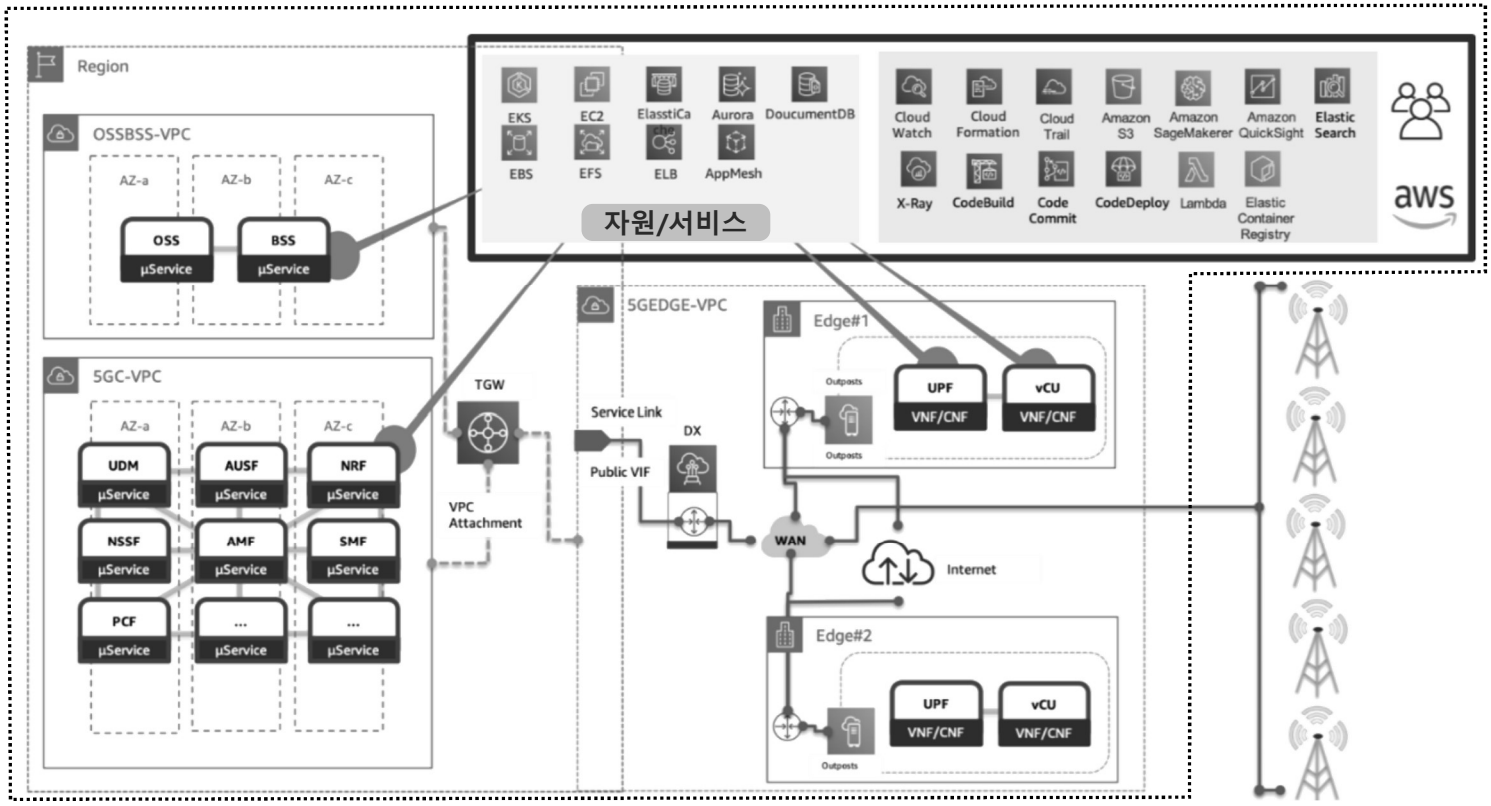


Source: VIRTUALIZED CELLULAR NETWOKS WITH NATIVE CLOUD FUNCTIONS, Iria Míguez González

DAY 2: ENHANCED MOBILE BROADBAND

❖ Reference architecture of 5G network (AWS)

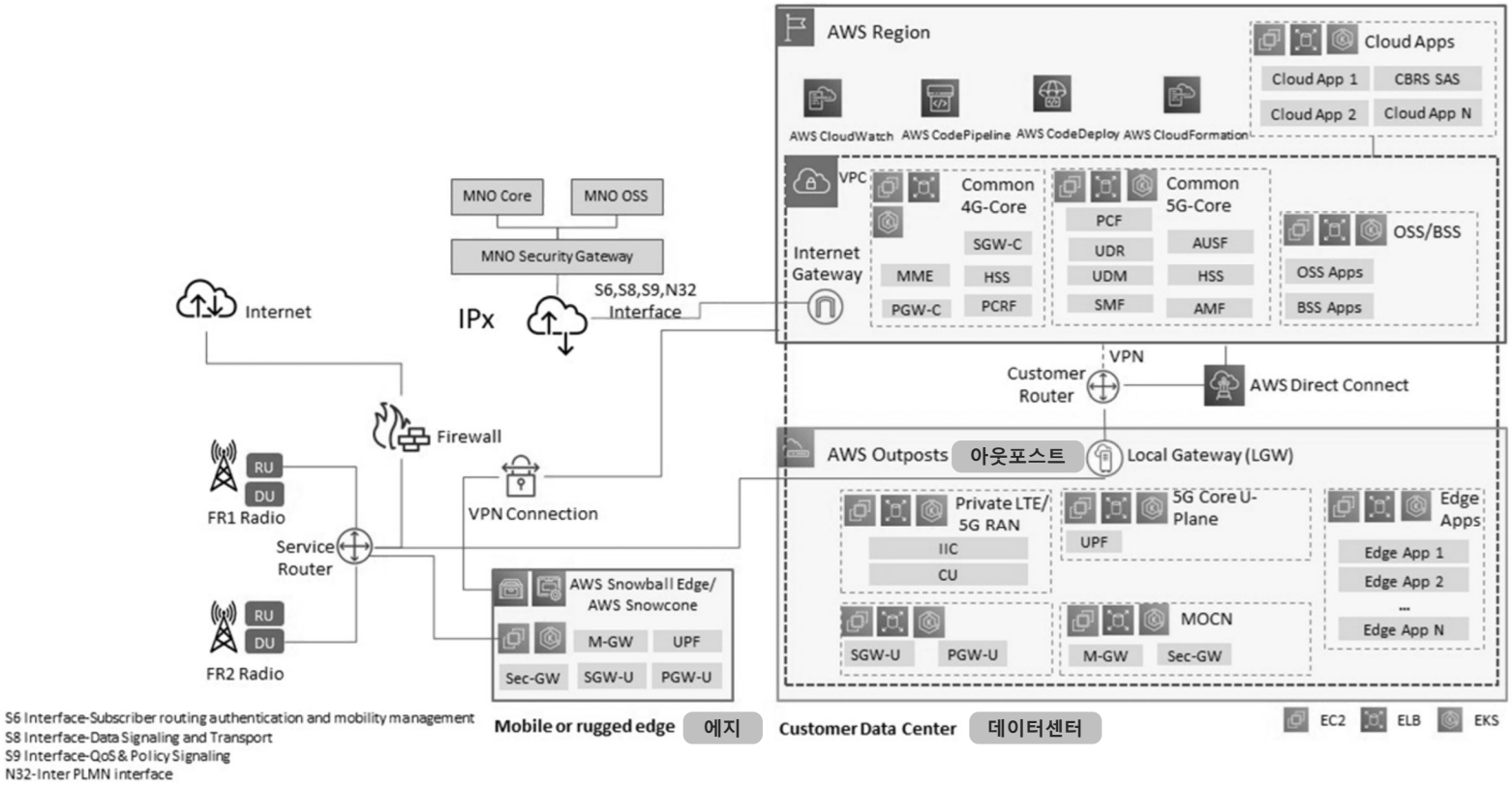
MSA



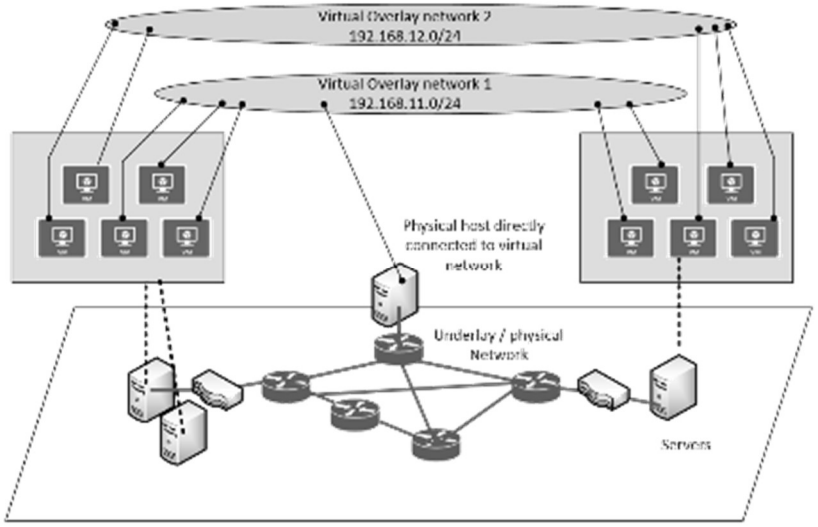
Source: 5G Network Evolution with AWS, July 2020

DAY 2: ENHANCED MOBILE BROADBAND

❖ **Private 4G/5G on AWS, Deloitte Private Networks Lab Houston.**

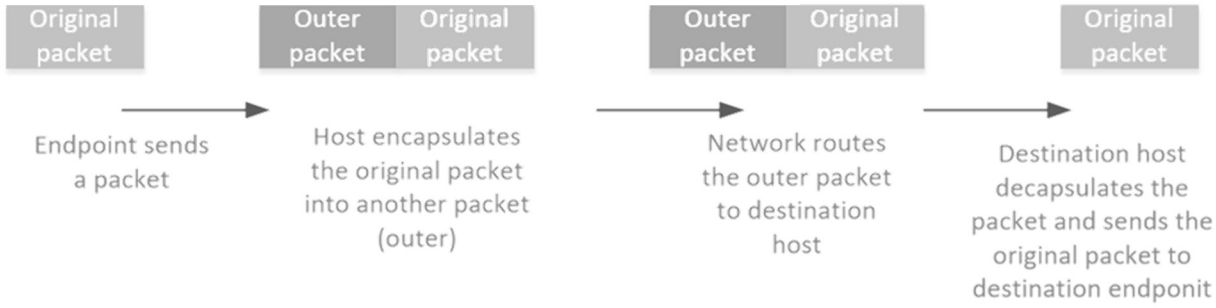


❖ Packet Transfer Steps in an Overlay Network



VXLAN (Virtual Extensible LAN) 사용시 고려

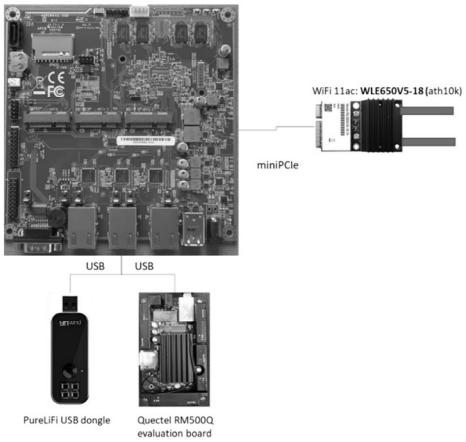
- **Maximum Ethernet Frame Size**
- **Multicast**

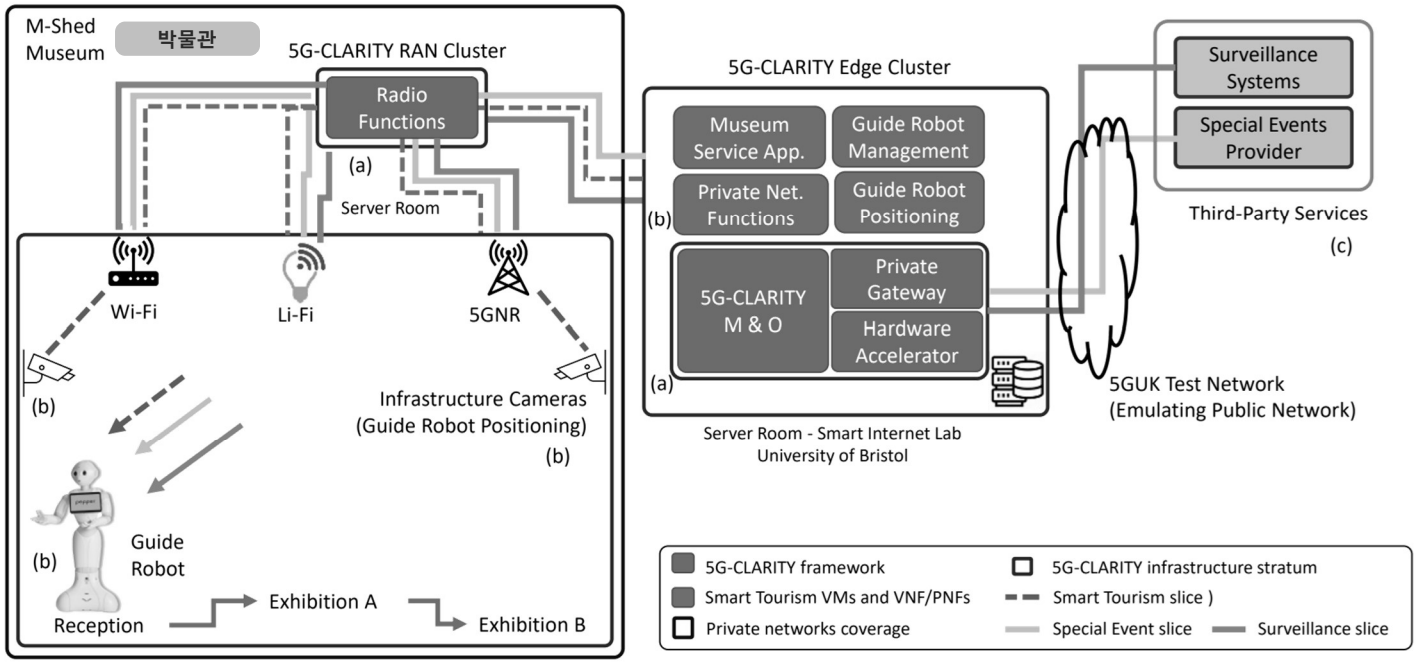


DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G-CLARITY proposed architecture

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

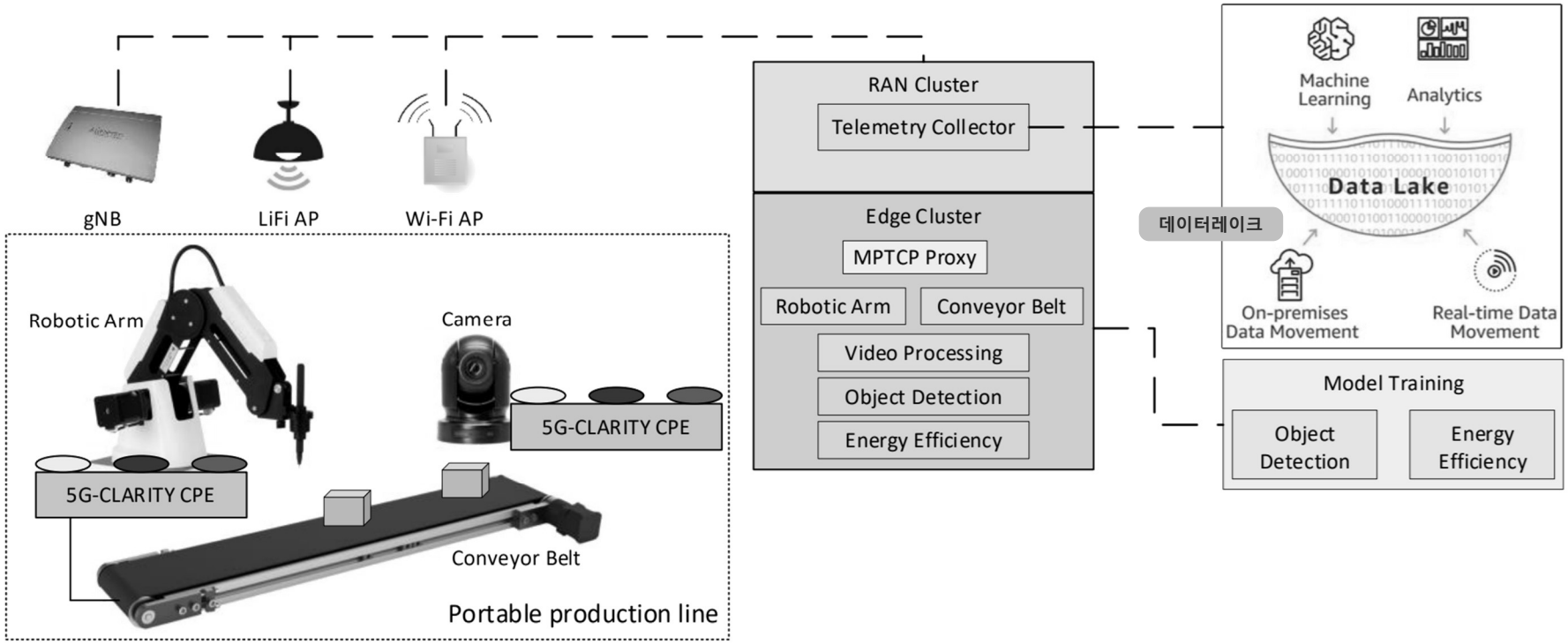




Source: 5G-CLARITY [H2020-871428], Mir Ghoraishi(GIGASYS)

DAY 2: ENHANCED MOBILE BROADBAND

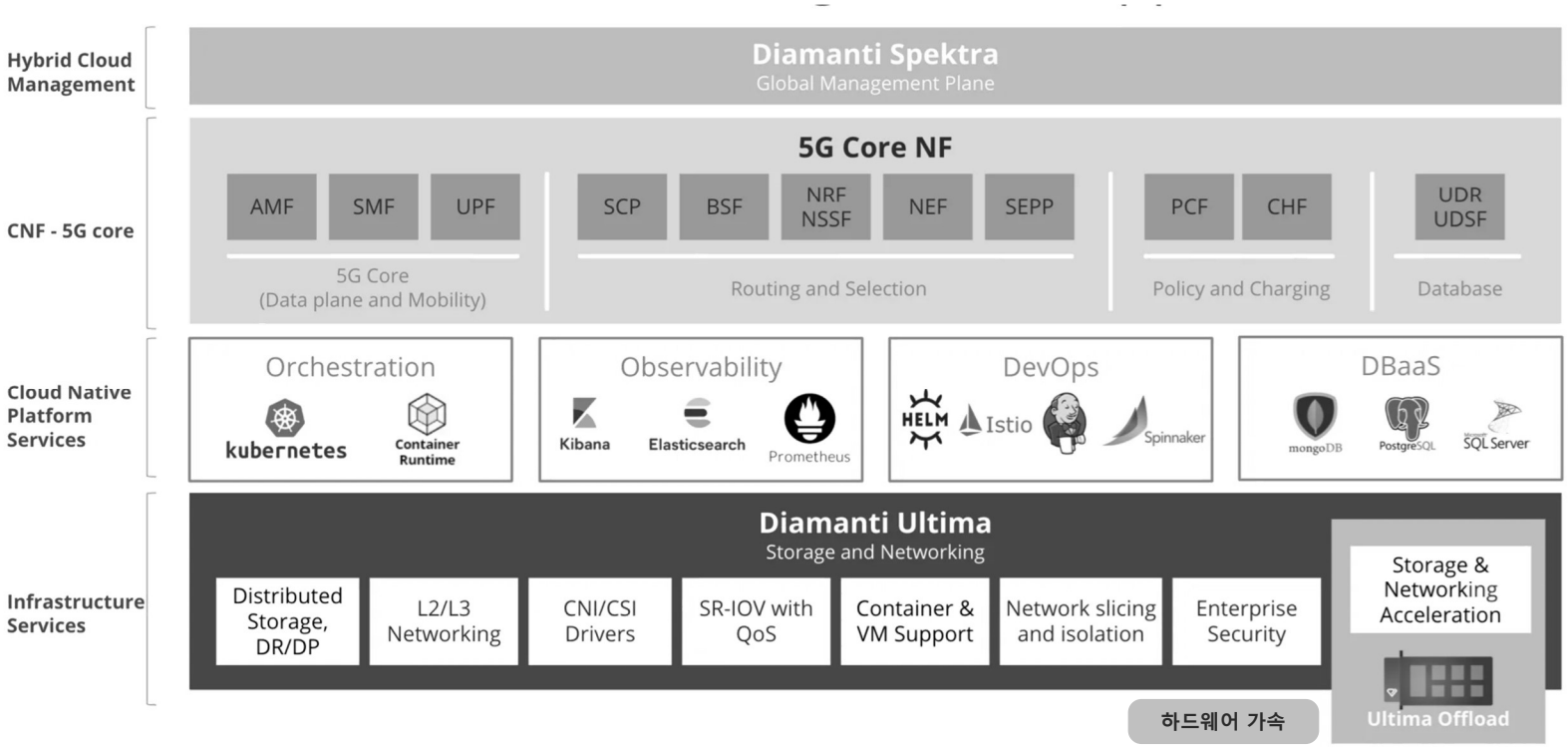
❖ Production line testbed and its integration to 5G-CLARITY system architecture



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

DAY 2: ENHANCED MOBILE BROADBAND

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

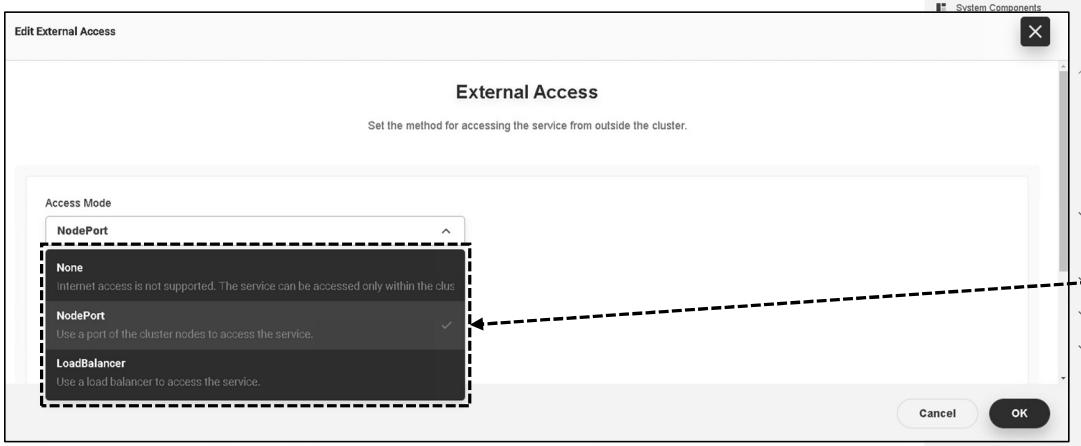


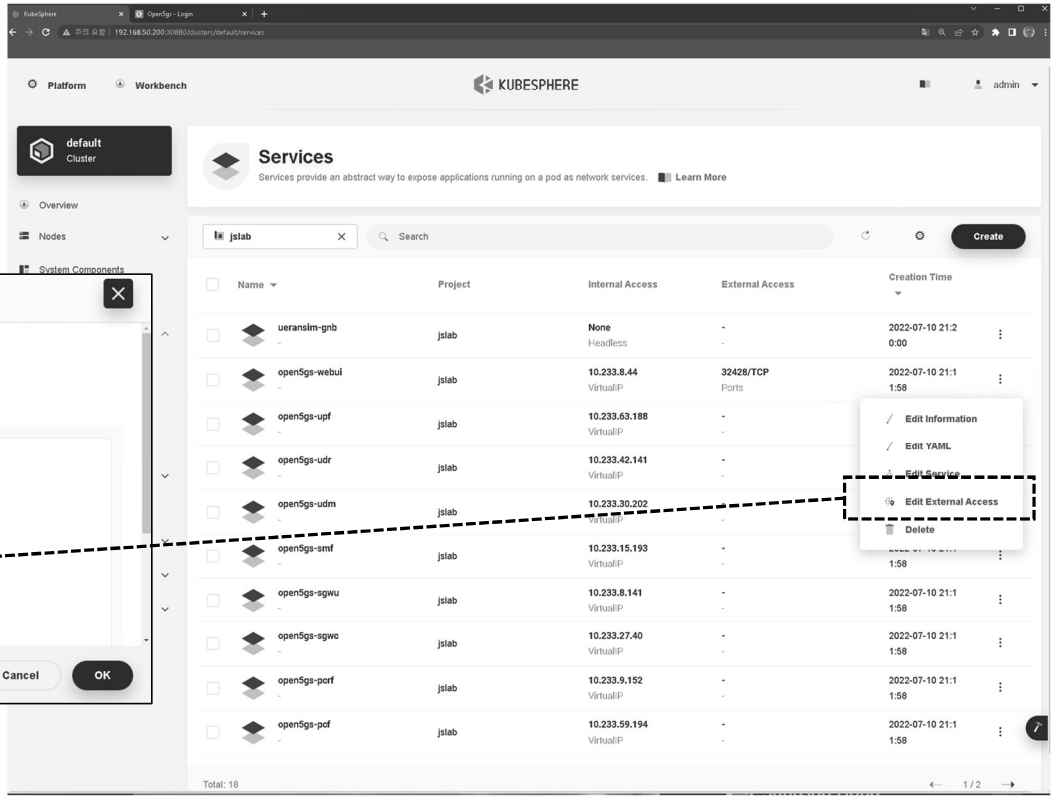
Source: https://diamanti.com/tutorial-5g-core-on-diamanti/

DAY 2: ENHANCED MOBILE BROADBAND

❖ Deploying 5G core network on Kubernetes: 포트 노출 정책

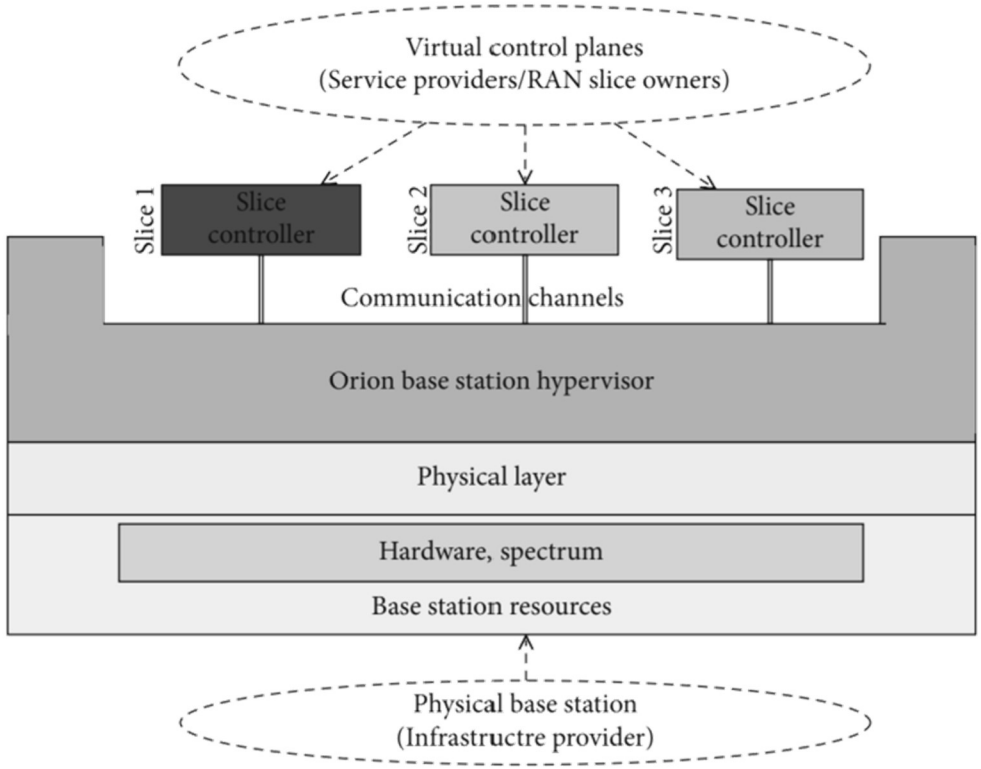
1. None
2. External Access for NodePort
3. External Access for LoadBalancer





DAY 2: ENHANCED MOBILE BROADBAND

❖ **High level of Orion testbed architecture**

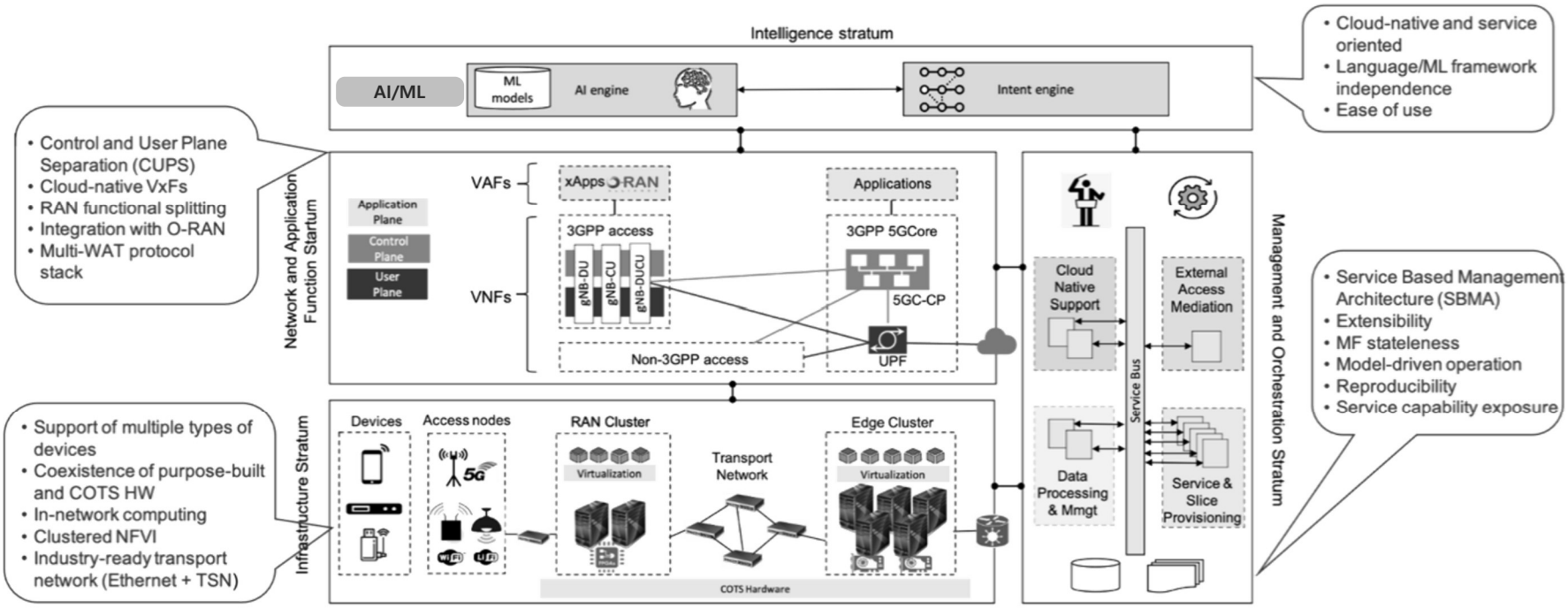


Wireless Communications and Mobile Computing, Volume 2021, Article ID 6655216, 26 pages, https://doi.org/10.1155/2021/6655216

DAY 2: ENHANCED MOBILE BROADBAND

❖ 5G-CLARITY proposed architecture

• 5G-CLARITY system architecture



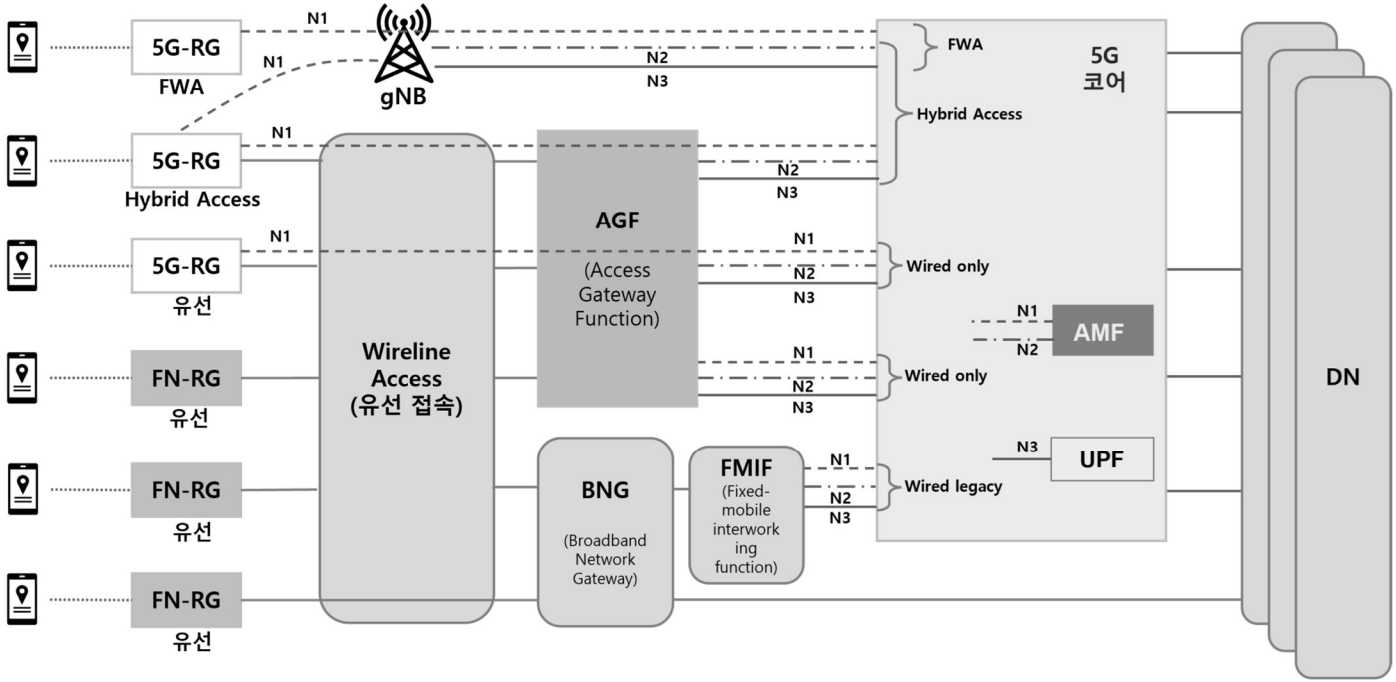
Source: 5G-CLARITY [H2020-871428], Mir Ghoraishi(GIGASYS)


THANK
YOU

DAY 2: BACKUP

❖ FMC(Fixed Mobile Convergence)

- 5GCN을 통한 FMC용 액세스 네트워크 시나리오



A Tutorial on Trusted and Untrusted non-3GPP Accesses in 5G Systems, Mario T. Lemes ID , Cristiano B. Both ID , Antonio Oliveira Jr. ID , and Kleber V. Cardoso ID