5G 네트워크

(Day 5. Cloud Native 5G 인프라)

2022년 7월
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- Day 1: 5G 네트워크 기술
- 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

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➢ (별도) Day 4~5 시연/실습

- 개요
- 5 Nodes in One-box Lab (시연)
- 2 Box Lab (실습)
- Cloud Native 5G Network Testbed (실습)

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➢ Day 5: Cloud Native 5G 인프라

- Telco Cloud
- Cloud 기반 5G 서비스 제조사, 오픈소스
- 5G를 위한 클라우드 네트워킹
- 클라우드 네트워킹 기술과 이슈
- 실습. Cloud Native 5G Network (별도 교재)

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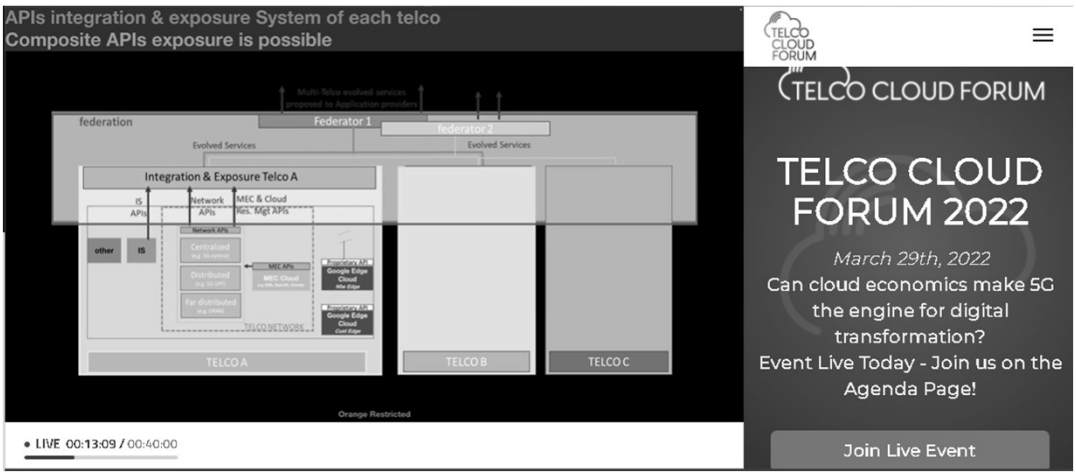
DAY 5: CLOUD NATIVE 5G 인프라

❖ Telco Cloud Forum 2022



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

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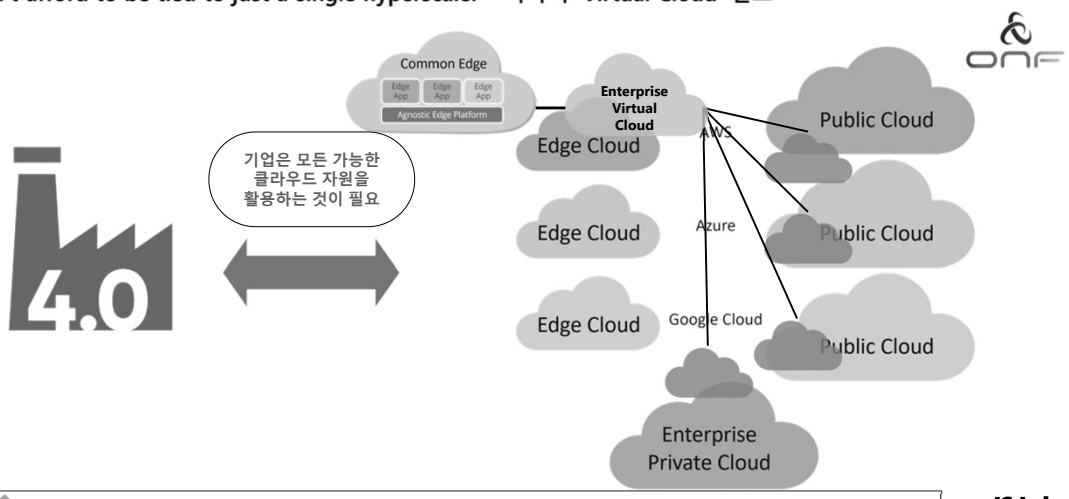
DAY 5: CLOUD NATIVE 5G 인프라

❖ 멀티클라우드는 기업의 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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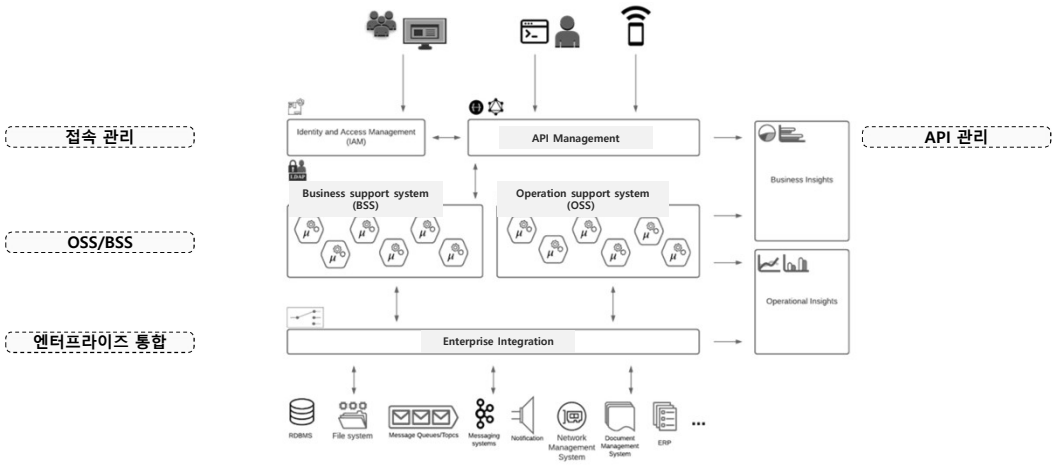
DAY 5: CLOUD NATIVE 5G 인프라

❖ 서비스 모델(예): Reference Architecture for telecom enterprise platform



Source: https://medium.com/codex/reference-architecture-for-a-telecom-enterprise-application-platform-257769a4a8d0

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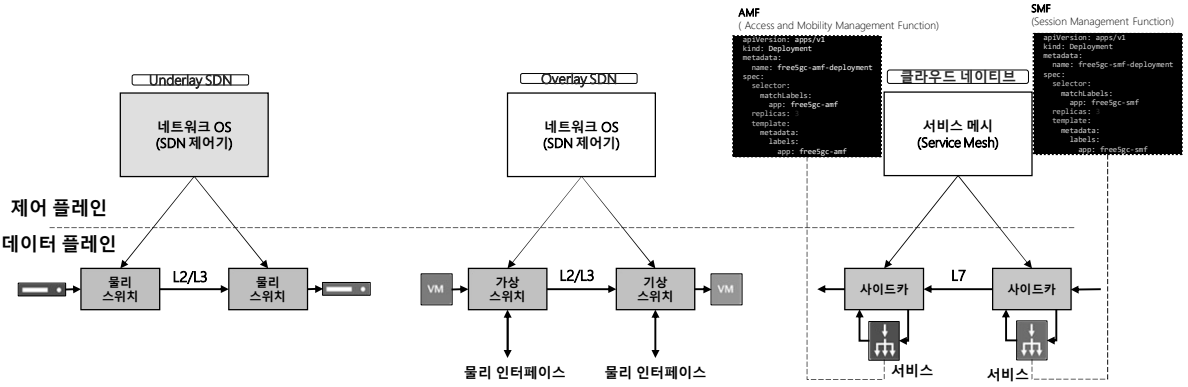
❖ 데이터센터의 오버레이 SDN (가상 네트워크)

- 오버레이 SDN의 분산처리: dSwitch, dRouter, dFW, dLB (VM 이동시 보안 정책 유지)
- 전용 제어기(SDN Controller) 사용
- Overlay/Underlay (물리/가상) 연결: VxLAN 프로토콜 사용 (VLAN, Multicast, VxLAN 헤더)



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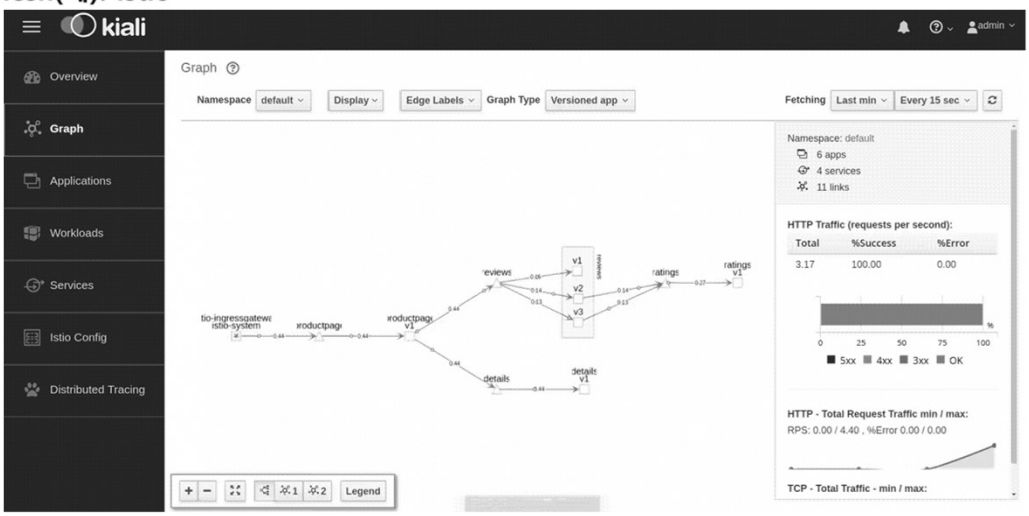
❖ Service Mesh(예): Istio



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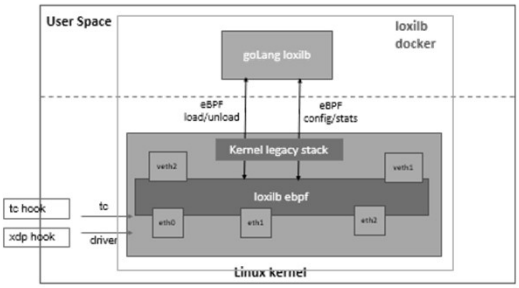
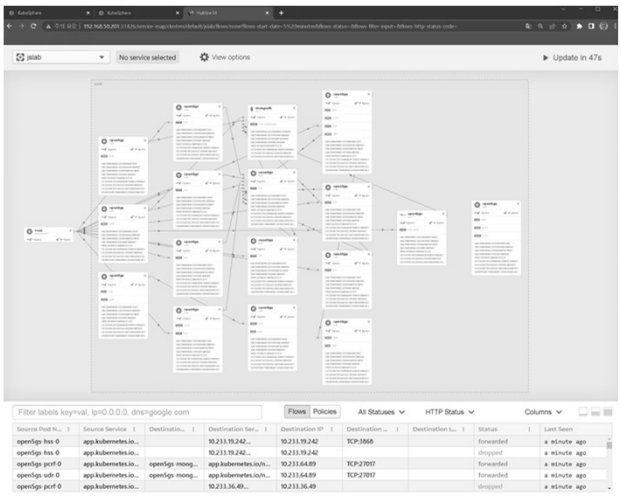
❖ eBPF @ K8s (예): open5GS





Source: https://github.com/loxilb-io/loxilbdocs/blob/main/docs/loxilbebpf.md?fbclid=IwAR3oR-Y67OOhowQhOR4neUje72Zq3MdA34-fm1bAlKLAUoFEBdmuX5D418Q

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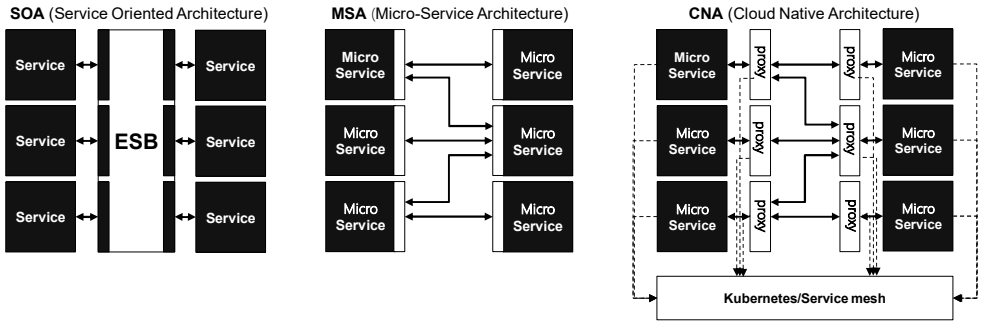
DAY 5: CLOUD NATIVE 5G 인프라

- ❖ Service Oriented Architecture (SOA)
- ❖ Microservice architectures (MSA)
- ❖ Cloud Native Architecture (CNA) Microservice Based Architecture



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DAY 5: CLOUD NATIVE 5G 인프라

❖ 마이크로서비스 아키텍처 MSA (TTA의 정의)

- MSA 대규모 소프트웨어 개발에 적용하기 위한 것으로 단독으로 실행 가능하고 독립적으로 배치될 수 있는 작은 단위(모듈)로 기능을 분해하여 서비스 하는 아키텍처.
- 작은 단위로 기능을 분할할 때 수직 방향의 기능별로 절단
- 절단된 독립적인 작은 모듈인 마이크로서비스는 공유나 프로세스 간 통신이 없이도 독립적으로 실행되며 운영 관리
- 마이크로서비스 간 연결은 응용 프로그래밍 인터페이스(API: Application Programming Service)를 이용
- 마이크로서비스는 표현이나 데이터 관리 등에 있어 기능적으로 완전
- 마이크로서비스 아키텍처 사용으로 개발자들이 클라우드 망을 통해 공유하고 협업하여 자유롭게 소프트웨어를 개발
- 개발 및 유지보수에 드는 시간과 비용이 절감
- 기존 모놀리식(monolithic) 방식과 반대되며, 서비스 지향 아키텍처(SOA: Service-Oriented Architecture) 방식보다 더 세분화

Source: http://www.tta.or.kr/data/weeklyNoticeView.jsp?pk_num=5193 - depleted

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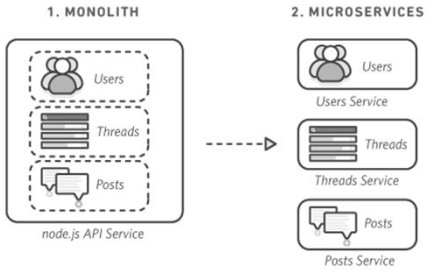
❖ 마이크로서비스 (아마존 AWS의 MSA 정의)

- 마이크로서비스는 소프트웨어가 잘 정의된 API를 통해 통신하는 소규모의 독립적인 서비스로 구성되어 있는 경우의 소프트웨어 개발을 위한 아키텍처 및 조직적 접근 방식입니다. 이러한 서비스는 독립적인 소규모 팀에서 보유합니다.
- 마이크로서비스 아키텍처는 애플리케이션의 확장을 용이하게 하고 개발 속도를 앞당겨 혁신을 실현하고 새로운 기능의 출시 시간을 단축할 수 있게 해 줍니다.



Source: https://aws.amazon.com/ko/microservices/

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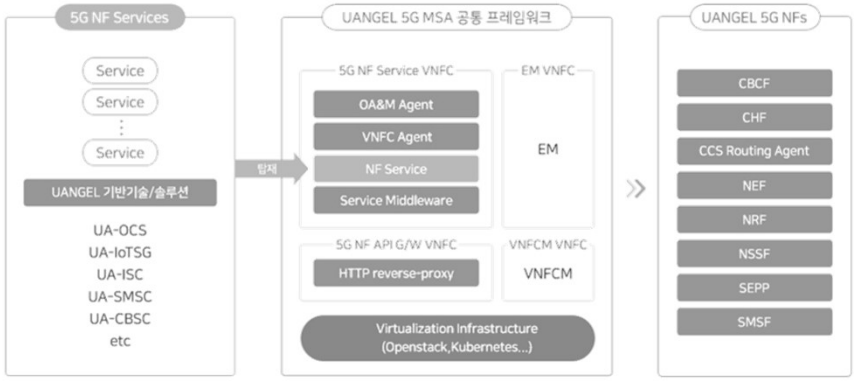
DAY 5: CLOUD NATIVE 5G 인프라

❖ 유엔젤: 5G Core NF (Network Function)

- Service-Based Architecture(SBA)와 Micro Service Architecture(MSA)에 최적화되도록 개발되었으며, 다양한 오픈소스들을 활용하며, 서비스 개발 환경인 CI/CD 환경 구축을 통해 Cloud Native 구조를 실현



Source: http://www.uangel.com/kr/index.php/products/5g/5g-core/

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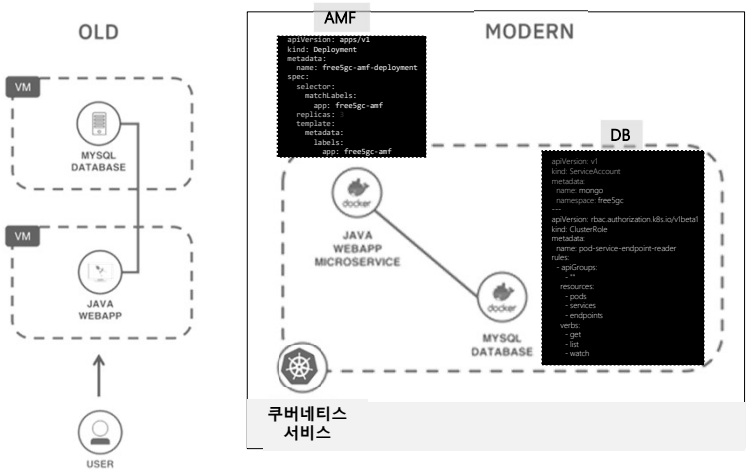
❖ **Modern App (예)**



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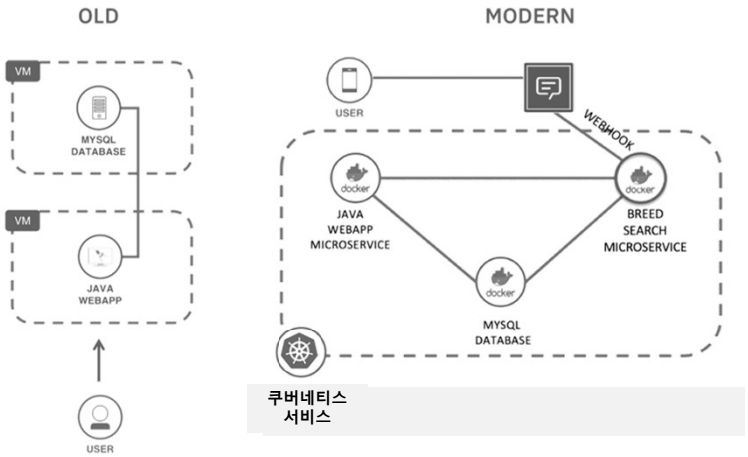
❖ **Modern App (예)**



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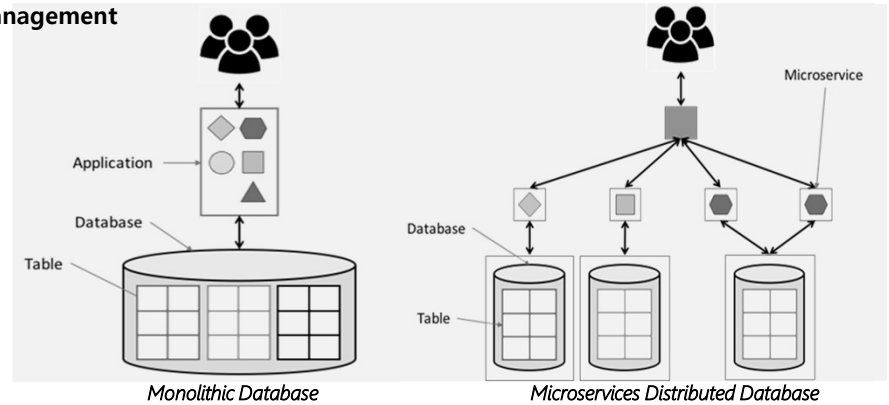
❖ **Refactoring (from Monolithic Module to MSA)**

- **Decentralized business and messaging rules**
- **Decentralized governance**
- **Decentralized data management**



Monolithic Database *Microservices Distributed Database*

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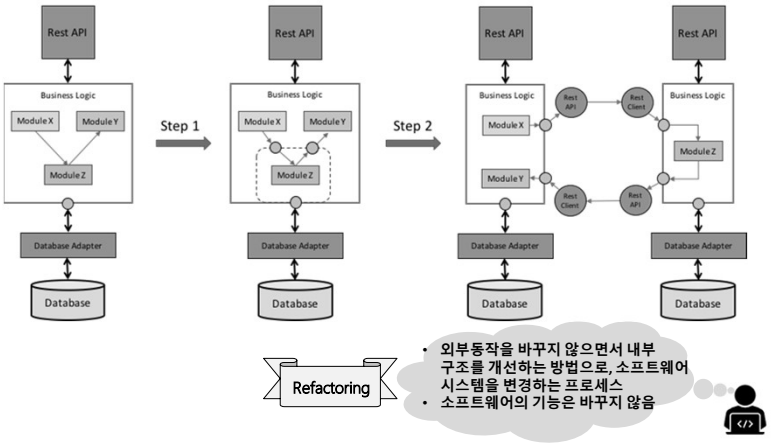
DAY 5: CLOUD NATIVE 5G 인프라

❖ **Refactoring (from Monolithic Module to MSA)**

- **서비스 모듈간 메시지 송수신 필요 (API 사용)**



Source: https://haloworld.tistory.com/24 [Halo World]

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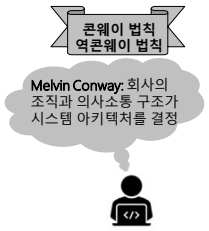
DAY 5: CLOUD NATIVE 5G 인프라

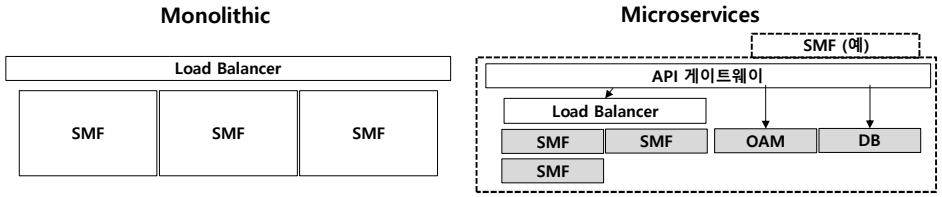
❖ 조직의 Learning Curve 고려

- 단일 마이크로서비스 (Standalone Microservice) 많이 필요시
- 과도한 의존성으로 시간이 많이 필요하고 코드의 품질이 낮아질 때
- 한가지 요소로 애플리케이션 장애 시

❖ 마이크로서비스 전환 시 추가 기능 고려

- 비즈니스 기능을 위한 서비스 연결
- 스탠드얼론 and/or 서비스의 부분 적용
- 각 엔지니어링 팀은 비즈니스 영역의 이해하고 책임을 소유





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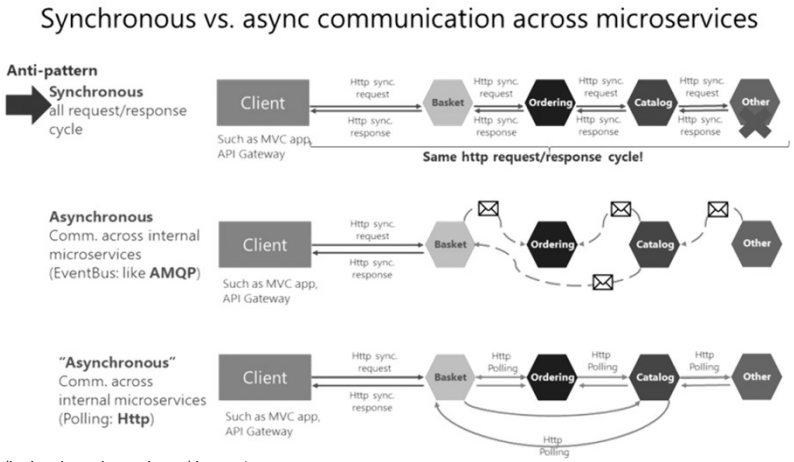
❖ 동기/비동기 통신



Source: https://www.emagiz.com/blog/loosely-coupled-applications-in-a-microservice-architecture/

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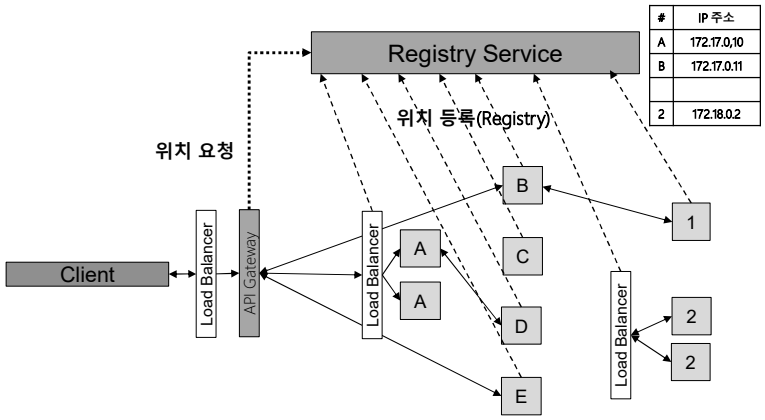
DAY 5: CLOUD NATIVE 5G 인프라

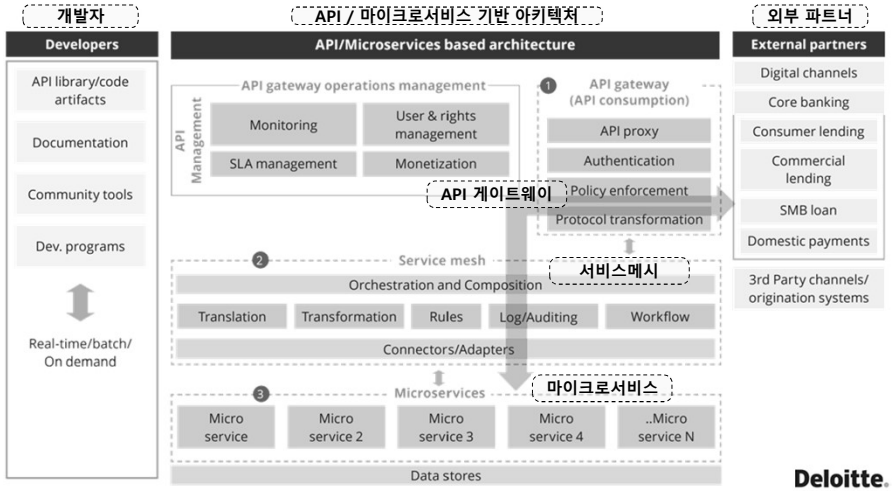
❖ 로드밸런서 추가 시 Service registry

- API Gateway는 모든 서비스에 대한 IP 주소를 알아야 하며 이의 DB 필요
- Registry 데이터의 안정성을 위해 오픈소스 사용(Consul이나 SkyDNS)



DAY 5: CLOUD NATIVE 5G 인프라

❖ Microservices-based architecture (예)

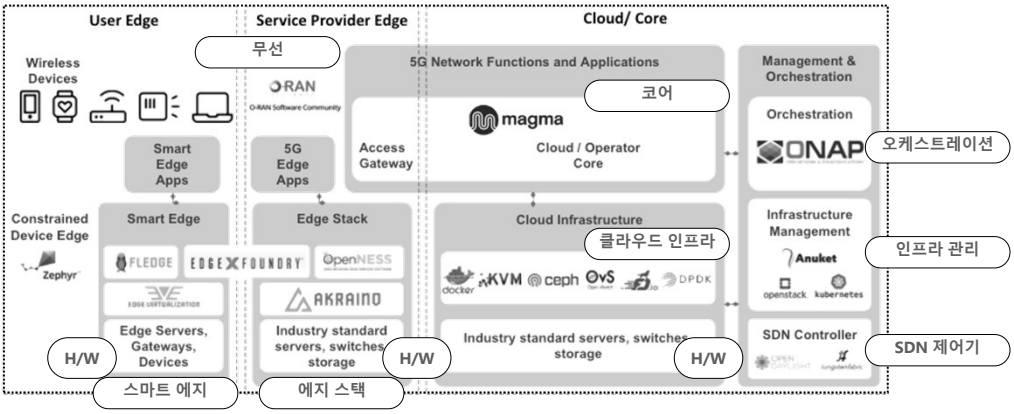


Source: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/financial-services/us-enabling-platform-banking-pov.pdf

DAY 5: CLOUD NATIVE 5G 인프라

❖ 리눅스재단(LF): 5G를 위한 오픈소스 프로젝트

LF Open Source Component Projects for 5G



Source: https://www.lfnetworking.org/5g-super-blueprint/

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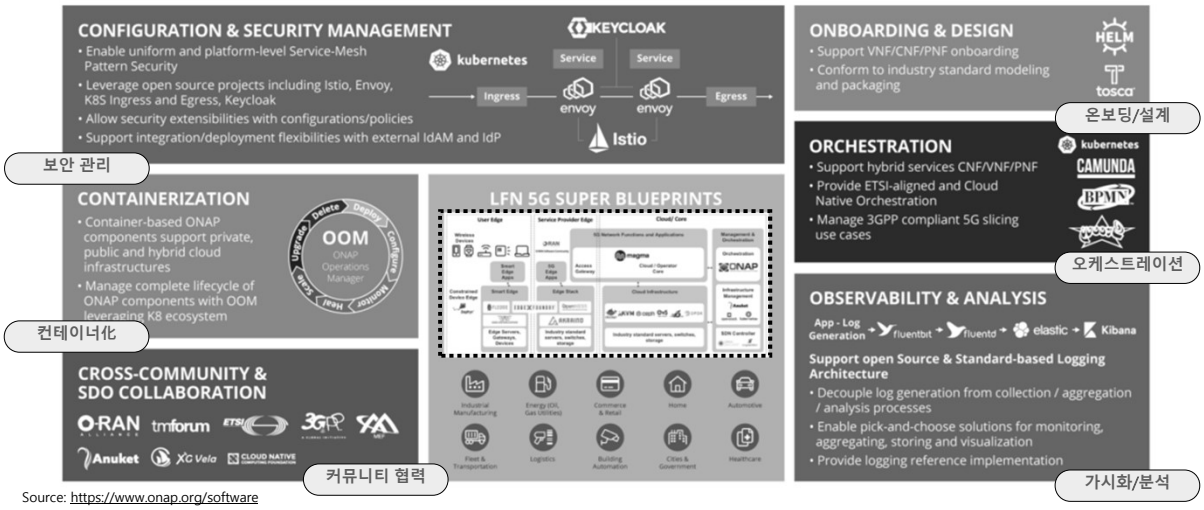
❖ 리눅스재단(LF): LFN 5G Super Blueprints (@ONAP)



Source: https://www.onap.org/software

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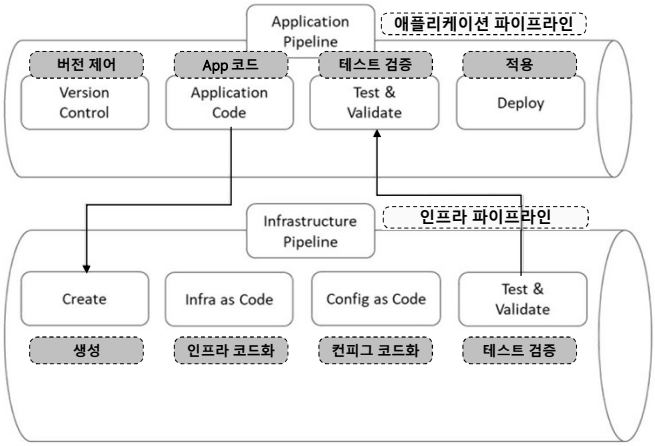
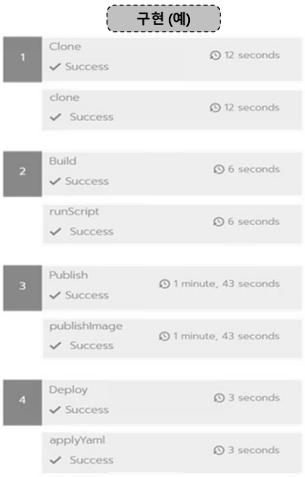
DAY 5: CLOUD NATIVE 5G 인프라

❖ 애플리케이션/인프라 (구분) - CI/CD 하이레벨 개념





Source: Mulder, Jeroen. Multi-Cloud Architecture and Governance: Leverage Azure, AWS, GCP, and VMware vSphere to build effective multi-cloud solutions. Packt Publishing.

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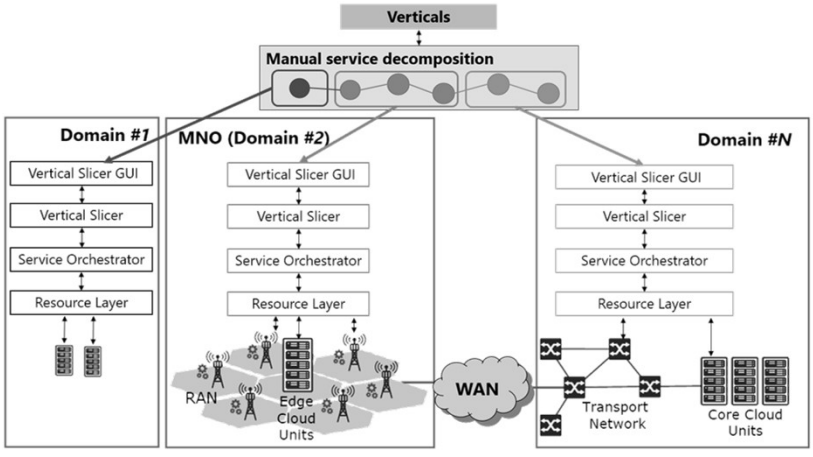
DAY 5: CLOUD NATIVE 5G 인프라

❖ Manual Vertical Service Decomposition



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

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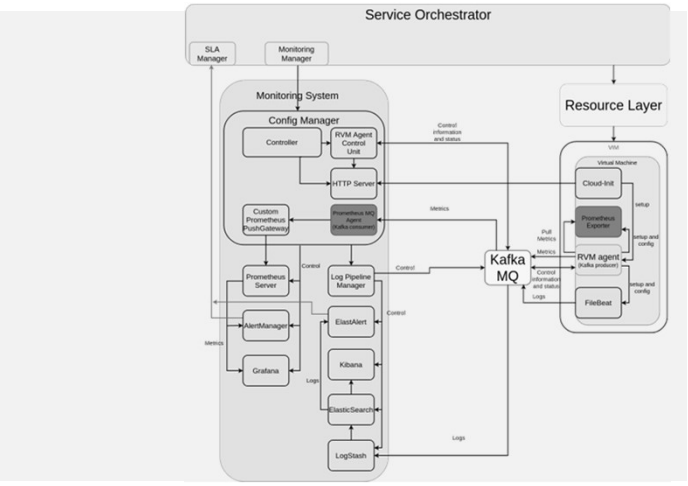
DAY 5: CLOUD NATIVE 5G 인프라

❖ Vertical-oriented Monitoring System Architecture

- 서비스 오케스트레이터
- 프로메테우스 (Prometheus)
- 카프카 (Kafka Message Queue)



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

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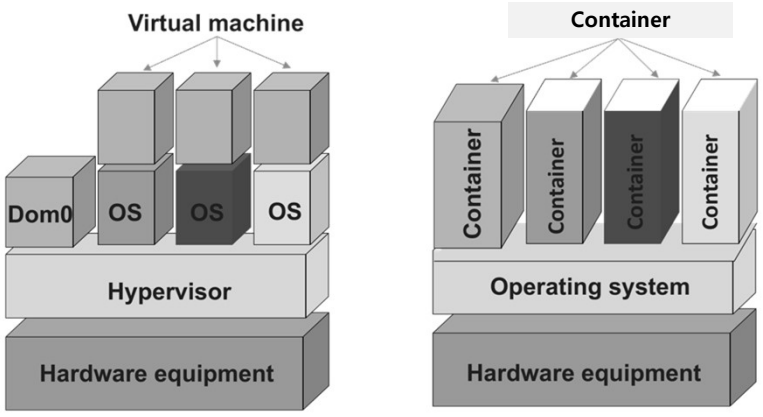
DAY 5: CLOUD NATIVE 5G 인프라

❖ 가상화와 컨테이너

- A virtualized machine
- or Container



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

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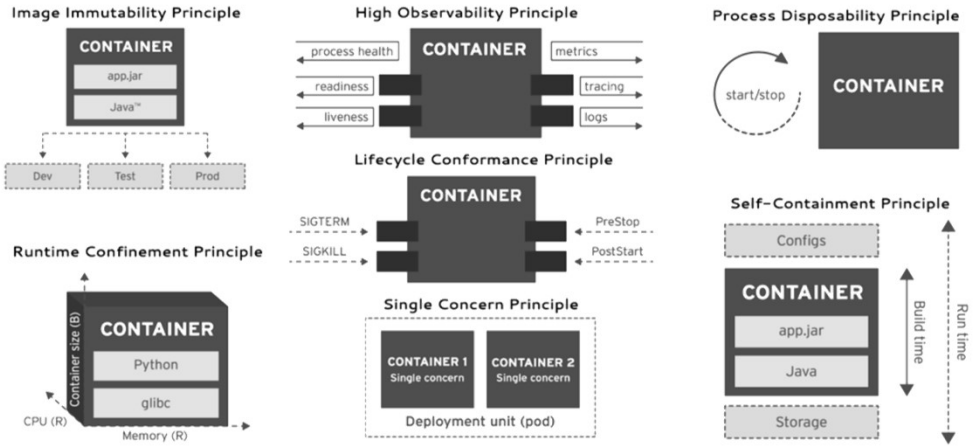
DAY 5: CLOUD NATIVE 5G 인프라

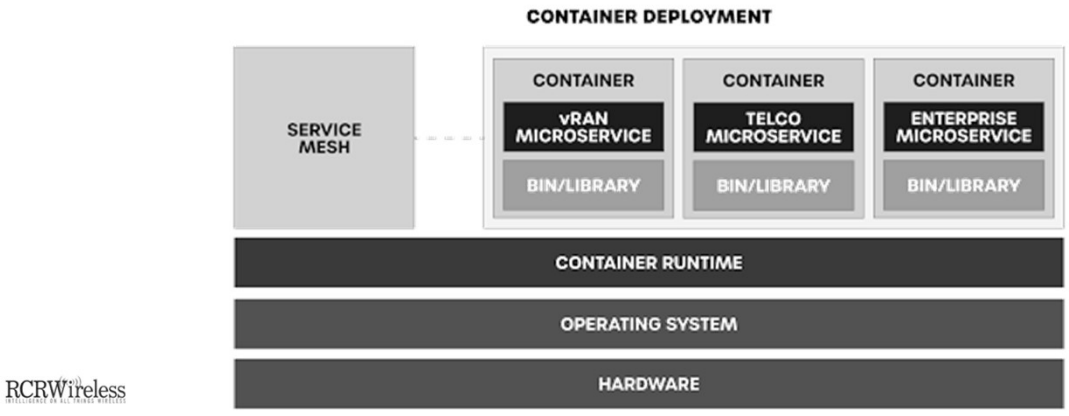
❖ Container-based Application Design



Source: https://kubernetes.io/blog/2018/03/principles-of-container-app-design/?fbclid=IwAR2oMrdP0d1Q6LXebtxNPnt-RS5DIlkClwpaMSL5mmW7VMaQb6hRV8hkd38

DAY 5: CLOUD NATIVE 5G 인프라

❖ Basics of cloud-native virtual and Open RAN architecture (예)

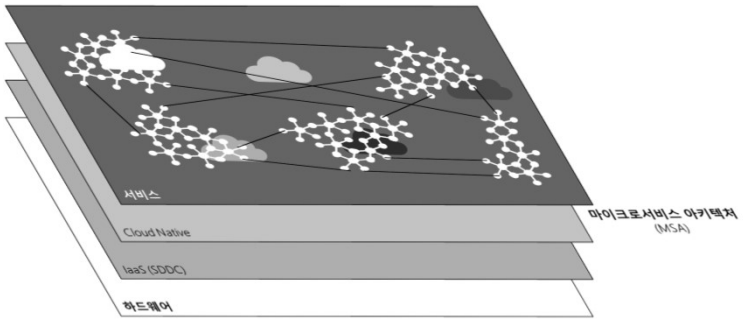


Source: https://www.rcrwireless.com/20210830/5g/how-to-secure-cloud-native-5g-virtual-and-open-ran-infrastructure

DAY 5: CLOUD NATIVE 5G 인프라

❖ 계층화 인프라

- 인프라의 계층별 추상화 (서비스에 집중)
- 계층간 격리와 정책 기반 서비스 노출
- 성능 개선 (계층 Offload)
- 연결 호환성



SDDC (Software Defined Datacenter), IaaS (Infrastructure-as-a-Service), MSA (Microservices Architecture)

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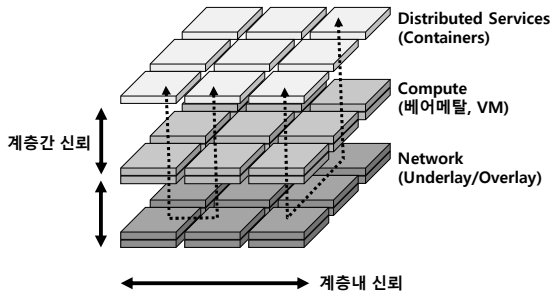
DAY 5: CLOUD NATIVE 5G 인프라

❖ 클라우드 계층 고려 인프라 보안

❖ 클라우드 계층 기반 보안 체계

- 클라우드/SDDC/하드웨어 계층간 격리
- 외부 서비스의 노출 정책 지정 (Ingress, LB, DMZ)
- 계층내 신뢰 정책 강화



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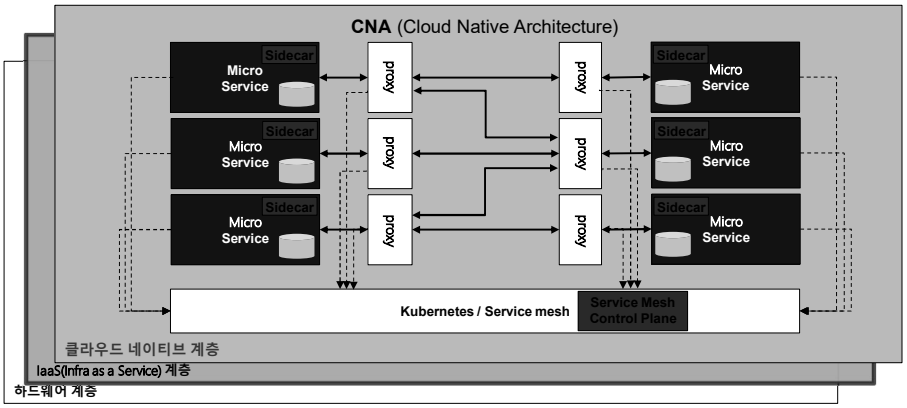
DAY 5: CLOUD NATIVE 5G 인프라

❖ CNA 의 서비스 메시 관리

- Sidecar Design Pattern: 라우터 내장 CB, LB, SD 내장
- CNCF의 'Istio'는 정책 강화 Telemetry 제공



CB (Circuit Breaker),
LB (Load Balancer),
SD (Service Discovery)

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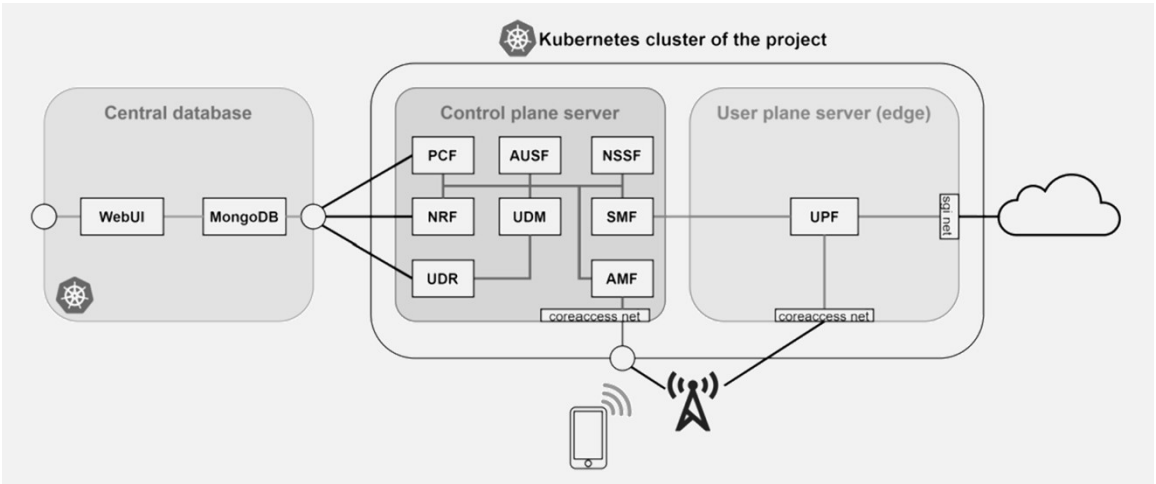
DAY 5: CLOUD NATIVE 5G 인프라

❖ Containerized core network approach



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

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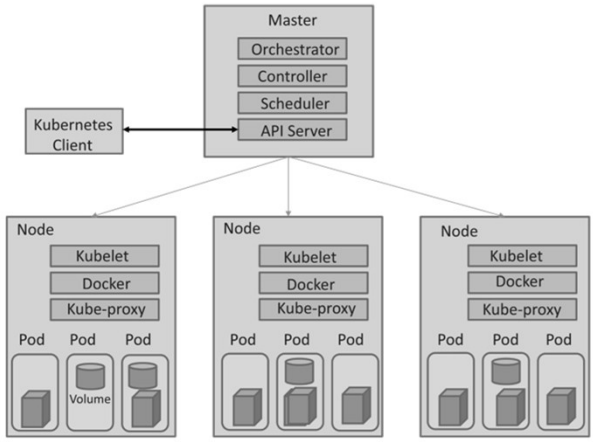
DAY 5: CLOUD NATIVE 5G 인프라

❖ 쿠버네티스(Kubernetes)

• **Architecture of the Kubernetes orchestrator**



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

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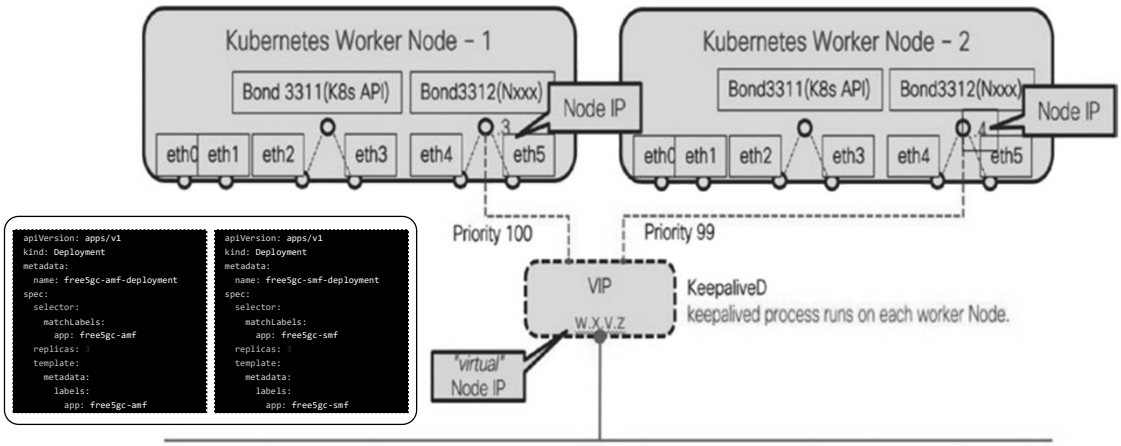
DAY 5: CLOUD NATIVE 5G 인프라

❖ Illustration of Service redundancy (배포)

Example – Part of CNF (AMF, SMF, et.)



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

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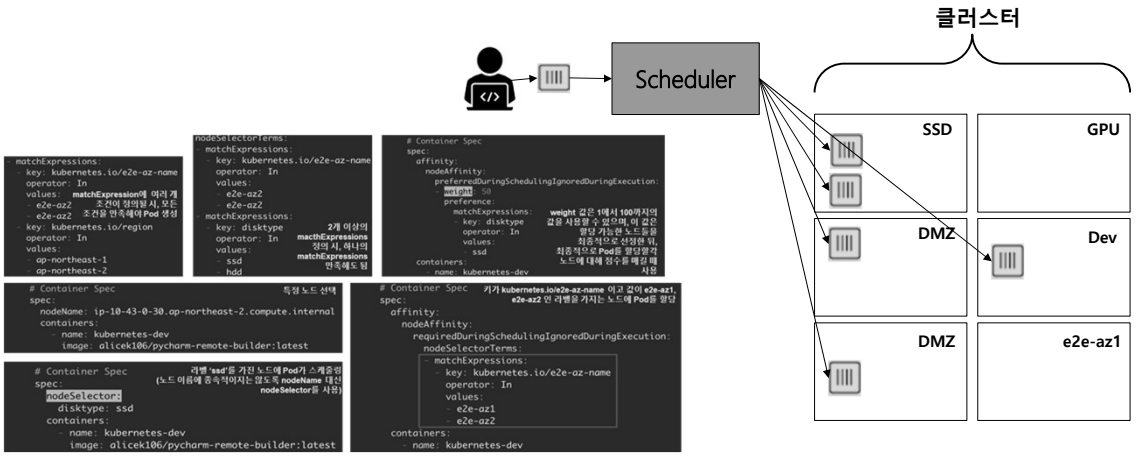
DAY 5: CLOUD NATIVE 5G 인프라

❖ Distributed system scheduler in action



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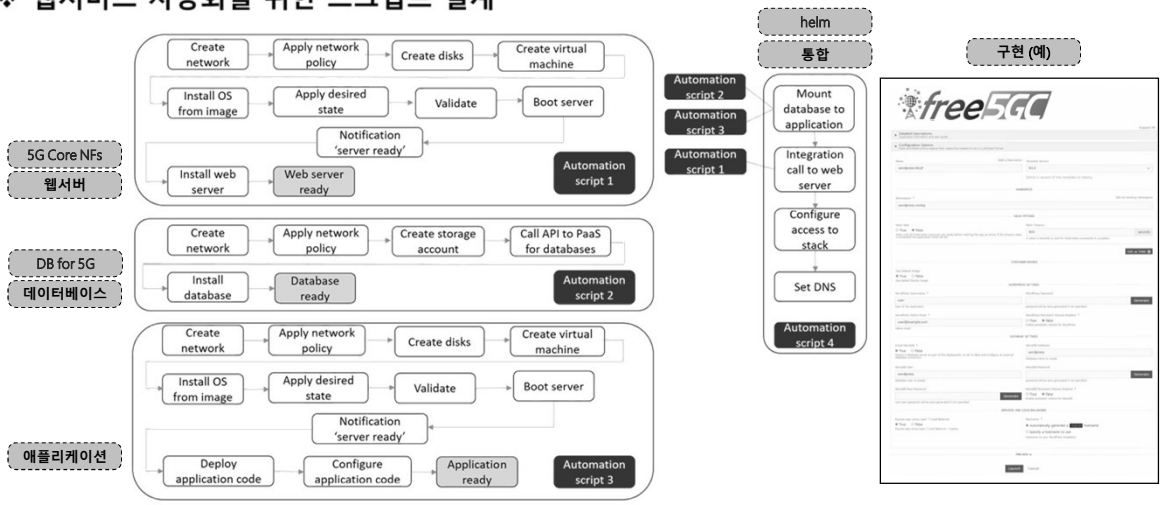
DAY 5: CLOUD NATIVE 5G 인프라

❖ 웹서비스 자동화를 위한 스크립트 설계



Source: Mulder, Jeroen. Multi-Cloud Architecture and Governance: Leverage Azure, AWS, GCP, and VMware vSphere to build effective multi-cloud solutions. Packt Publishing.

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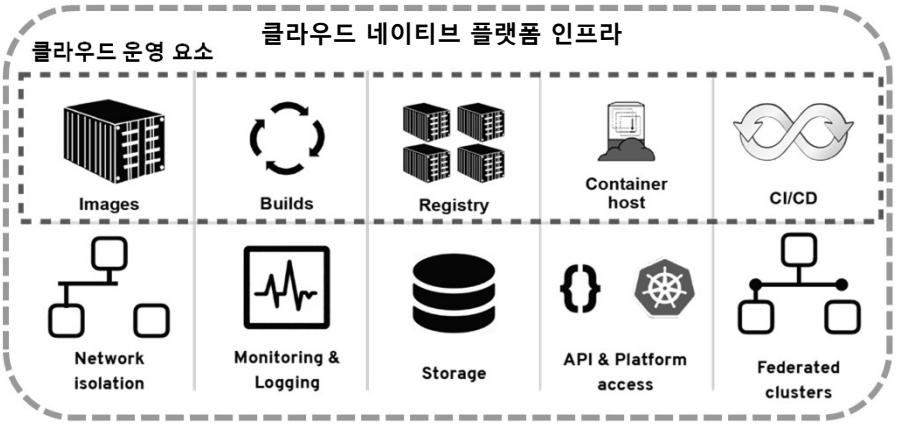
DAY 5: CLOUD NATIVE 5G 인프라

❖ 클라우드 인프라 구성 요소 고려 보안

- SDDC 추상화 운영 요소: 컴퓨팅, 스토리지, 네트워크, 관리, API 접속
- 클라우드 운영 요소: Images, Builds, Registry, Container Host, CI/CD



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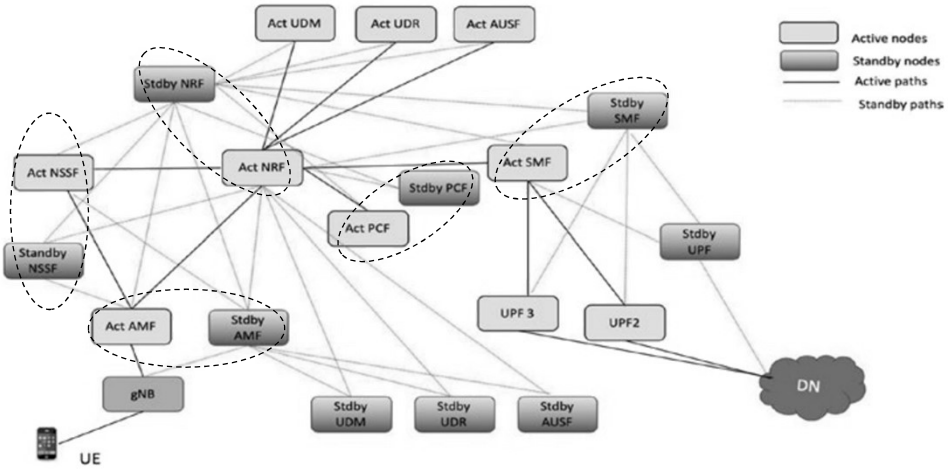
DAY 5: CLOUD NATIVE 5G 인프라

❖ 리던던트 레이아웃 (Redundancy layout for a simple Release15 5G SA network)



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

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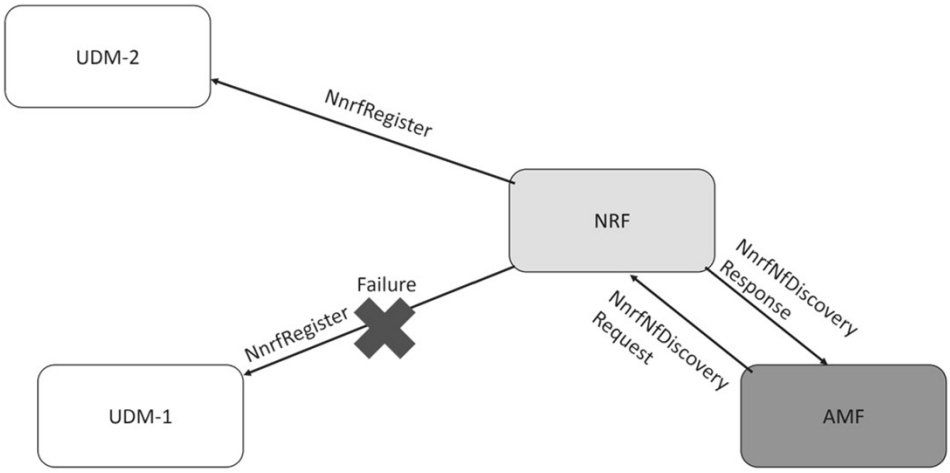
DAY 5: CLOUD NATIVE 5G 인프라

❖ NRF의 Node failure handling



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

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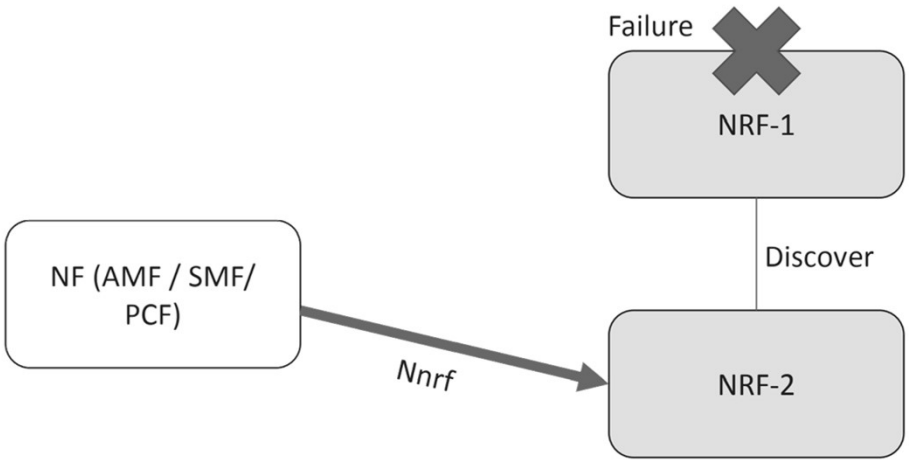
DAY 5: CLOUD NATIVE 5G 인프라

❖ NRF failure handling



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

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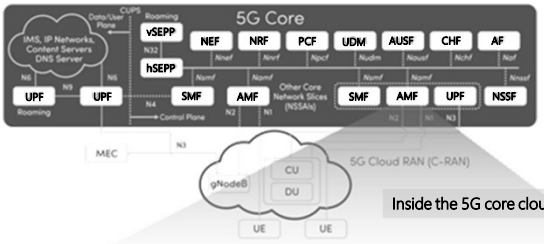
DAY 5: CLOUD NATIVE 5G 인프라

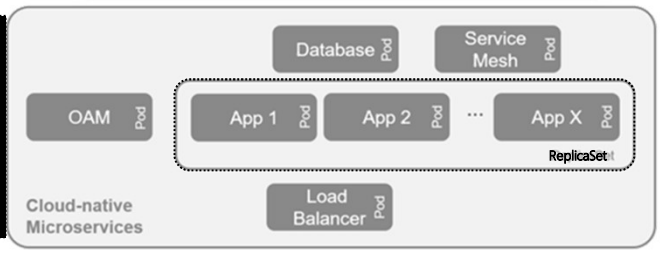
❖ 5G CNF의 MSA

• pods/functions (Kubernetes)



Inside the 5G core cloud-native 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
```



Source: https://www.spirent.cn/blogs/why-confidence-in-5g-cloud-performance-begins-with-resilience

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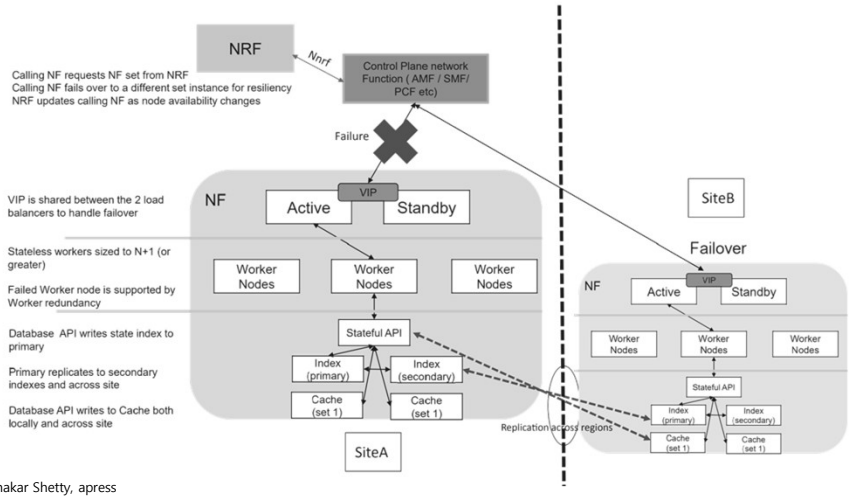
DAY 5: CLOUD NATIVE 5G 인프라

❖ Geographical redundancy for control plane network functions



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

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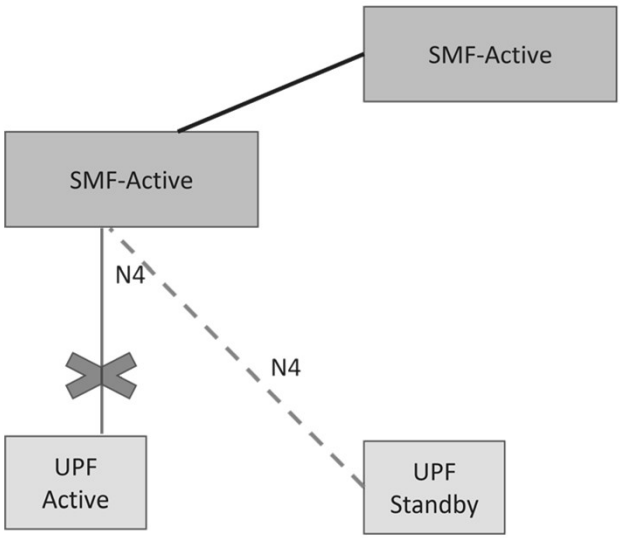
DAY 5: CLOUD NATIVE 5G 인프라

❖ 1:1 user plane redundancy



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

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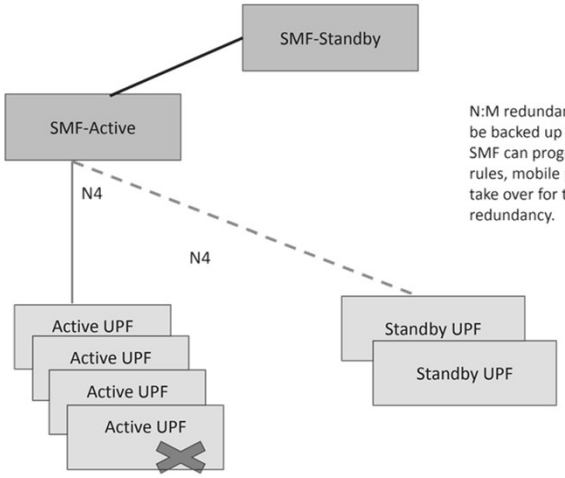
DAY 5: CLOUD NATIVE 5G 인프라

❖ N:M user plane redundancy



N:M redundancy requires state stored in the UPF and be backed up on the SMF
SMF can program a standby UPF with the required pcc-rules, mobile pools and session state information to take over for the failed UPF and provide data plane redundancy.

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

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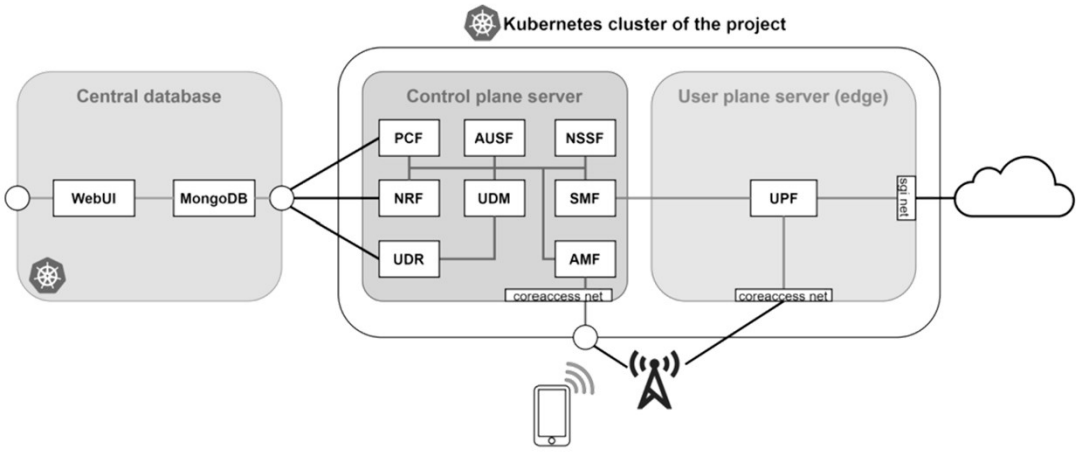
DAY 5: CLOUD NATIVE 5G 인프라

❖ Containerized core network approach



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

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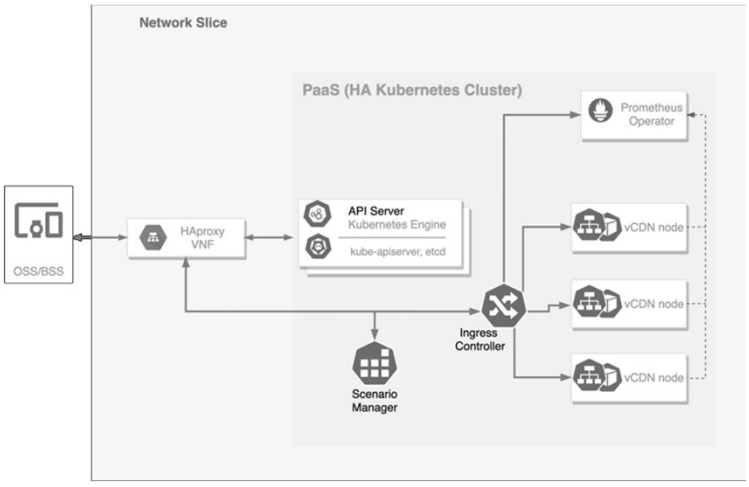
DAY 5: CLOUD NATIVE 5G 인프라

❖ CDN emulation leveraging PaaS



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

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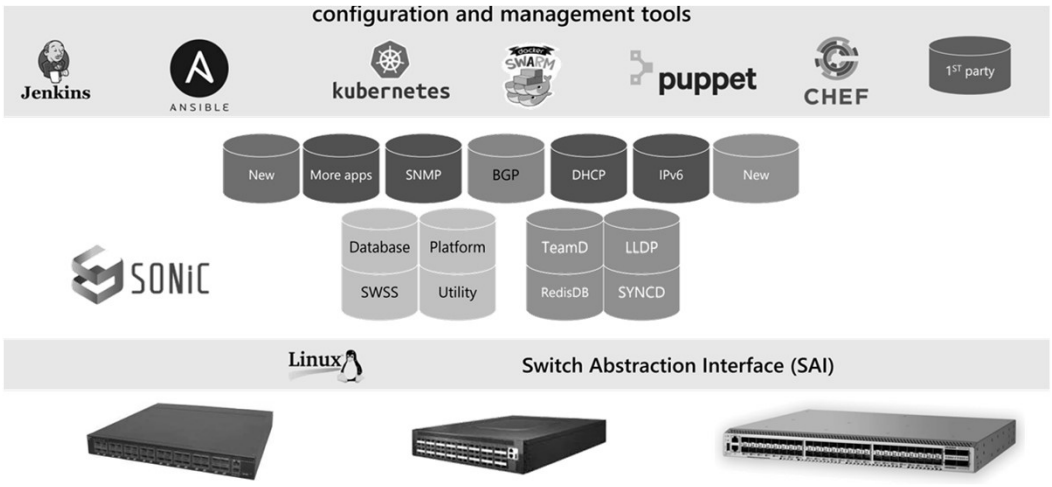
DAY 5: CLOUD NATIVE 5G 인프라

❖ **SONiC** (Software for Open Networking in the Cloud)



DAY 5: CLOUD NATIVE 5G 인프라

❖ **KubeEdge MEC SIG (예)**

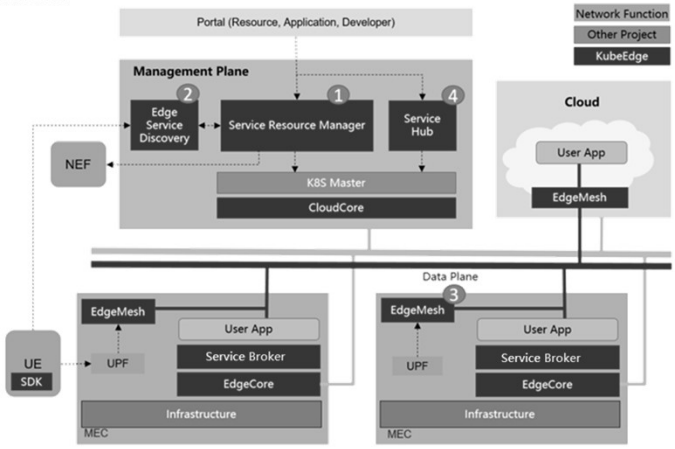
❖ **MEC SIG focuses on the following fields**

① **Service Resource Manager**

② **Edge Service Discovery**

③ **EdgeMesh**

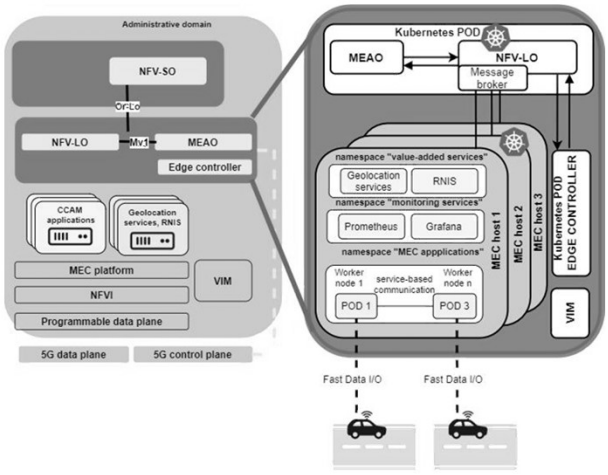
④ **ServiceHub**



Source: https://www.cncf.io/blog/2021/07/20/kubeedgemec-combining-the-kubernetes-ecosystem-with-5g/

DAY 5: CLOUD NATIVE 5G 인프라

❖ Cloud-native design overview of the 5G Edge Orchestration Platform in an ETSI MEC context



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

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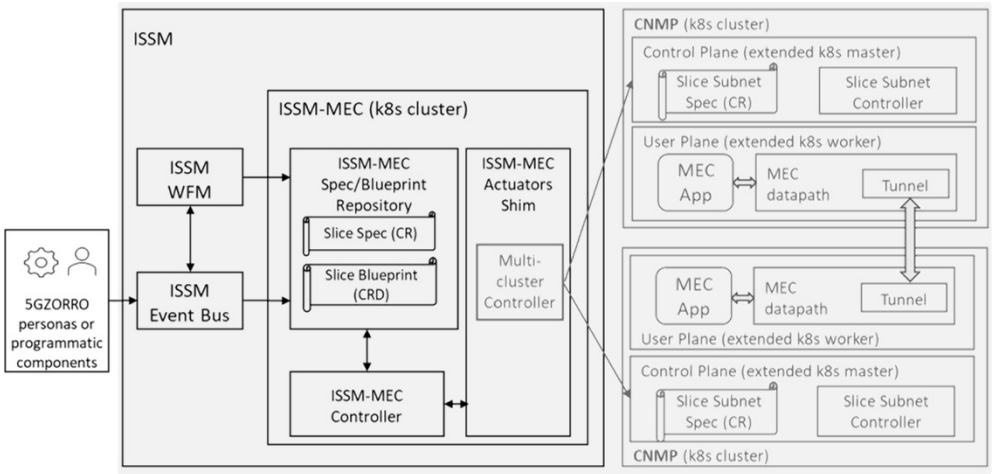
DAY 5: CLOUD NATIVE 5G 인프라

❖ Cloud-native MEC platform



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

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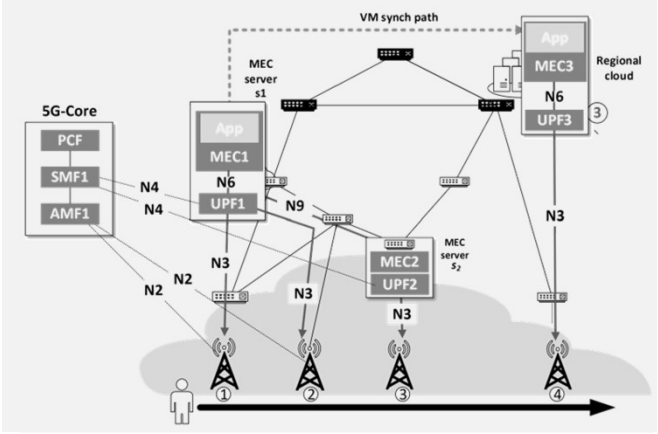
DAY 5: CLOUD NATIVE 5G 인프라

❖ Joint user handover and VM migration problem to ensure service continuity in MEC-assisted 5G environments.



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

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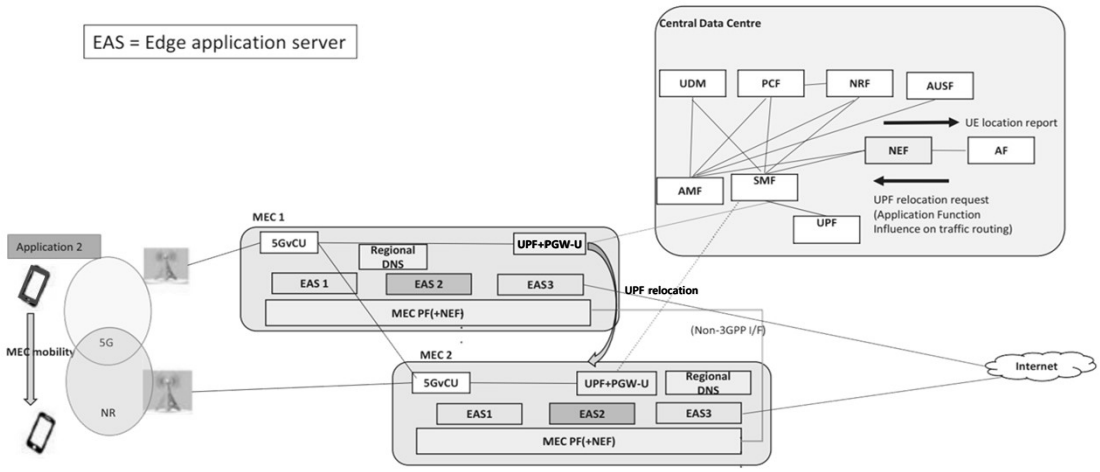
DAY 5: CLOUD NATIVE 5G 인프라

❖ Integrated MEC deployment in 5G network with UPF relocation



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

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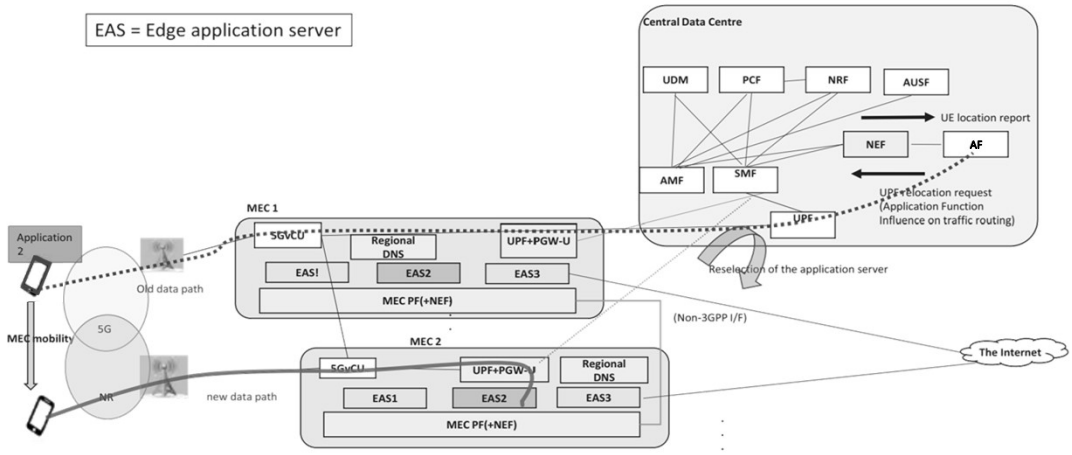
DAY 5: CLOUD NATIVE 5G 인프라

❖ Integrated MEC deployment in 5G network with application relocation



5G Mobile Core Network, Rajaneesh Sudhakar Shetty, apress

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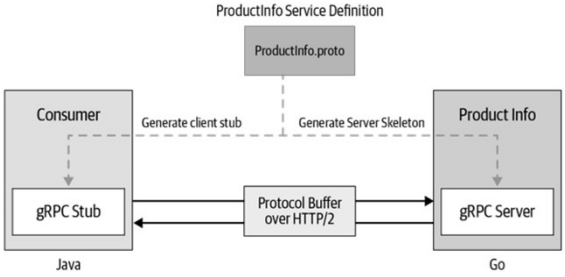
DAY 5: CLOUD NATIVE 5G 인프라

❖ A microservice and a consumer based on gRPC



		REST	gRPC
	Goal	REST (HTTP/JSON)	gRPC
COMPATIBILITY	Single source of truth	✗	✓
	Multi-platform + languages built in	✗	✓
	Handle non-breaking changes.	✗	✓
PERFORMANCE	Network: connection handling	Manual, 1 per call ✗	Built-in, Multi per conn ✓
	Speed: Transmission of data	Human-readable Text ✗	Binary ✓
	CPU: Improved resource usage	✗	✓
MAINTENANCE	Tracing	Manual ✗	Easy to plug in ✓
	Logging	Manual ✗	Easy to plug in ✓
	Monitoring	Manual ✗	Easy to plug in ✓

Source: https://swagger.io/tools/swaggerhub/

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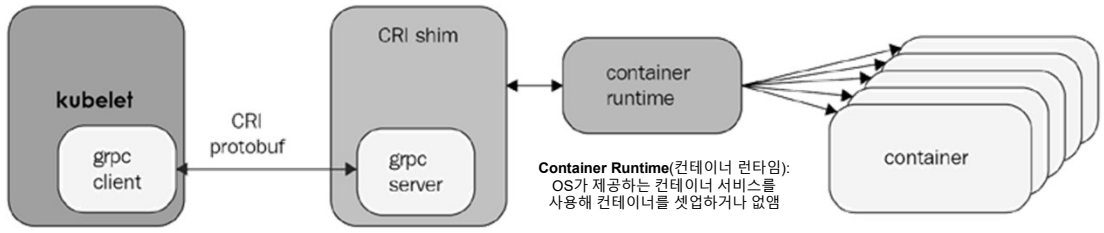
DAY 5: CLOUD NATIVE 5G 인프라

❖ The container runtime interface (CRI) flow diagram



kubelet은 K8s 클러스터내의 모든 모드에서 실행되는 에이전트

CRI: kubelet이 **컨테이너** 런타임을 호출할 수 있는 **인터페이스**

Container Runtime(컨테이너 런타임): OS가 제공하는 컨테이너 서비스를 사용해 컨테이너를 셋업하거나 없앰

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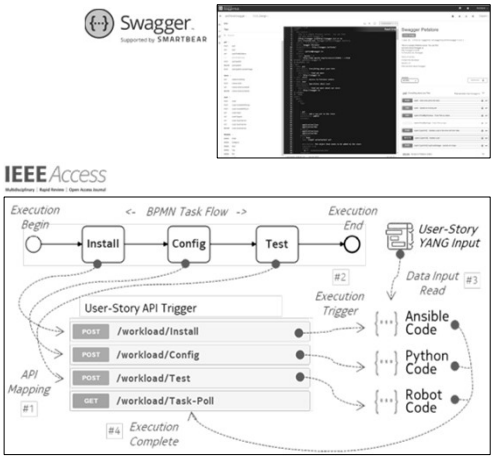
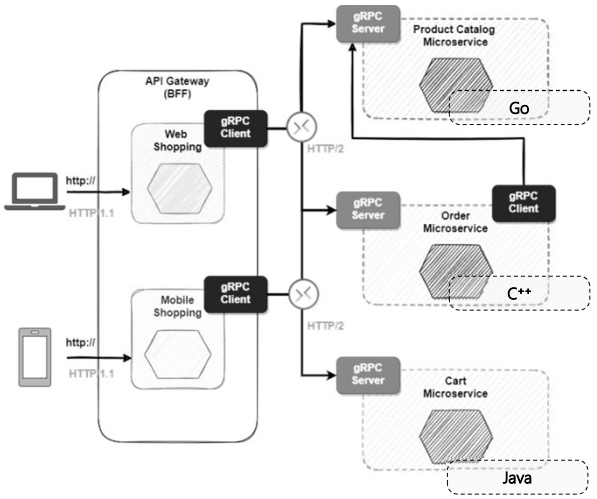
DAY 5: CLOUD NATIVE 5G 인프라

❖ gRPC application architecture (예)





Source: https://techdozo.dev/grpc-for-microservices-communication/

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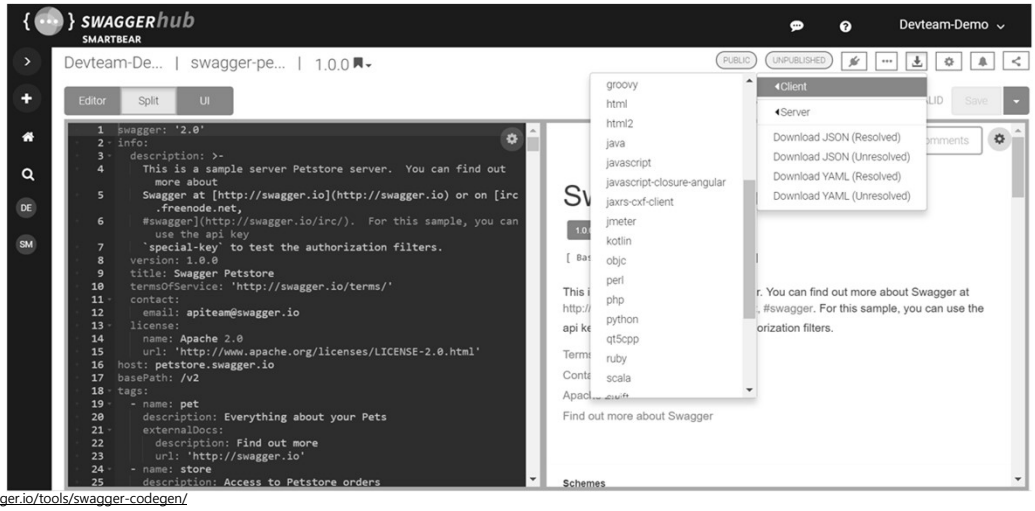
DAY 5: CLOUD NATIVE 5G 인프라

❖ Swagger(예): Generate Server Stubs & Client SDKs in SwaggerHub

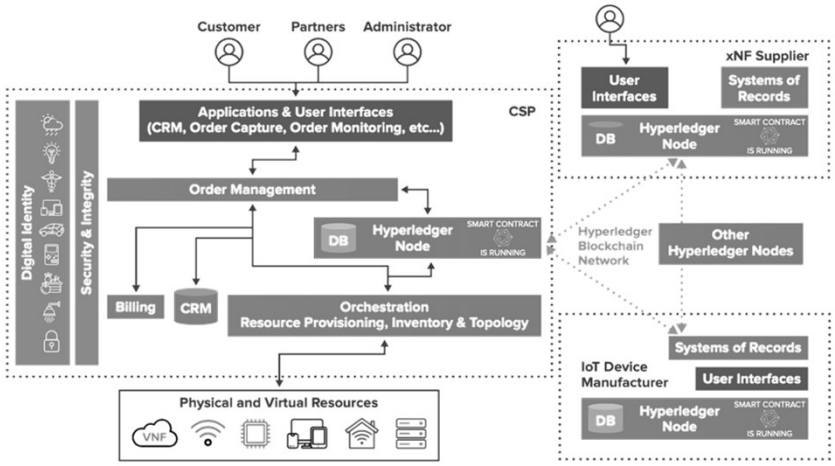


Source: https://swagger.io/tools/swagger-codegen/

DAY 5: CLOUD NATIVE 5G 인프라

❖블록체인 토폴로지 (Inter-carrier Charges @ Telecom)

- (예) Hyperledger-based IoT Networks



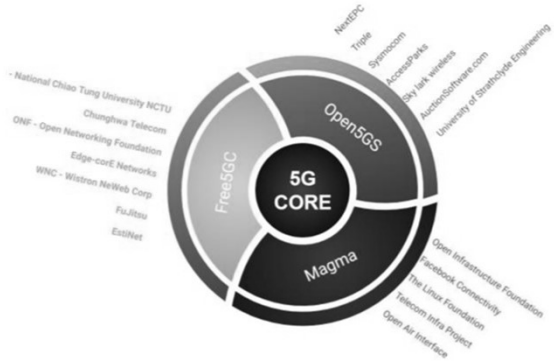
Source: https://www.hyperledger.org/tag/telecom

DAY 5: CLOUD NATIVE 5G 인프라

❖ Analysis for Comparison of Framework for 5G Core Implementation

TABLE I. ELEMENTS NECESSARY TO DEPLOY

Magma	Open5GS	Free5GC
Docker/Container + bare metal	Docker/Container	Virtual Machine



Major supporters of Core 5G development.

Source: 2021 International Conference on Information Science and Communications Technologies (ICISCT) | 978-1-6654-3258-0/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICISCT52966.2021.9670414

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DAY 5: CLOUD NATIVE 5G 인프라

❖ 5G Core 오픈소스 비교 (예): free5GC vs Open5GS vs magma

항목	free5GC	Open5GS	magma
UE 등록, 인증, 세션확립 및 패킷 전송	**3GPP Release15.3**	**3GPP Release16**	**3GPP Release15**
슬라이스 식별자 단위 라우팅 및 품질 제어	슬라이스 식별자로 UPF 분배 가능, 품질 제어(QoS)는 구현되지 않음	슬라이스 식별자로 UPF 배분 가능 품질 제어(QoS)는 구현되지 않음	슬라이스 분배 미실장 DNN*1 단위로 우선 제어는 가능
CU 분리	5G 코어 네트워크에서 UPF를 분리 구축 가능	5G 코어 네트워크에서 UPF를 분리 구축 가능	C / U를 분리하지 않고 소형 일체형 텐테나화하여 배치
MEC 분배(ULCL)	각 IMSI에 대해 대상 IP 주소로 배분 가능	미실행	MSI마다 5tuple로 배분 가능
전송 성능 (1G 인터페이스) ※RAN/UE 및 트래픽 부하는 계측기를 사용	DL:916Mbps, UL:932Mbps (롱 패킷: 1400byte UDP) DL:36Mbps, UL:116Mbps (짧은 패킷: 66byte UDP)	미시험	미시험
동시 접속 UE 수	11UE까지		
UE (SIM)	GUI에서 UE 등록, 업데이트, 삭제	GUI에서 UE 등록, 업데이트, 삭제	GUI에서 UE 등록, 업데이트, 삭제
구성 설정, 모니터링, 운영	• 구성 설정은 Yaml 파일을 직접 편집합니다. • 편집 부분을 많이 이해하기 어렵다. • 알람은 시스템 로그 파일에서 확인	• 구성 설정은 Yaml 파일을 편집해야 합니다. • 편집 부분을 많이 이해하기 어렵다. • 알람은 시스템 로그 파일보다 확실	오케스트레이터로 관리 제어, GUI에 구성 설정 및 상태 모니터링 가능
도입 용이성	요구 하드웨어 사양 낮음, 매뉴얼대로 도입 간단	요구 하드웨어 사양 낮음, 매뉴얼대로 도입 간단	요구 하드웨어 사양 낮음, 매뉴얼대로 도입 간단
4G RAN과 5G RAN을 동시 수용	5G 코어만 구현하므로 4G RAN 수용 불가	4G 코어와 5G 코어 모두 구현	4G, 5G, Wi-Fi 모두 수용 Converged Core 개발 검토 중

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DAY 5: CLOUD NATIVE 5G 인프라

❖ **Collaborative Cloud - Edge:** A Declarative API orchestration model for the NextGen 5G Core

• **Open-source projects for virtualized 4G and 5G mobile packet core**

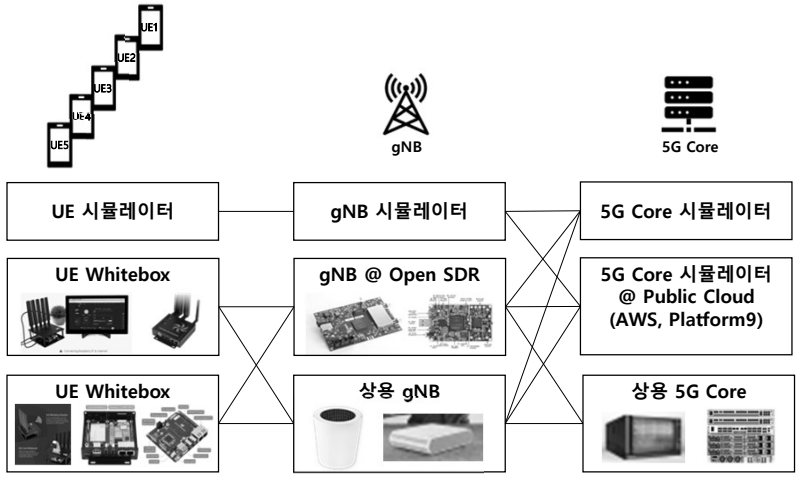
OSS Project	*Language*	*License*	*4G*	*5G*	*CNF*	*Active Contributors*
OpenAirInterface [29]	C	Apache v2.0	yes	yes	wip*	OpenAir Software Alliance EUROCOM
NextEPC	C	GNU AGPLv3	yes	wip*	wip *	NextEPC
corenet [30]	Python	GPL-2.0 License	yes	no	no	Corenet
openLTE [31]	C++	GNU AGPLv3	yes	no	no	openLTE
open5GS	C	GNU AGPLv3	yes	yes	yes	Open5GS
OMEC	C++	Apache v2.0	yes	yes	no	ONF, Intel, Deutsche Telekom, Sprint, AT&T
free5GC [32]	Go, C	Apache v2.0	no	yes	wip*	Free5C
srsLTE [33]	C++	GNU AGPLv3	yes	no	no	srsLTE
OpenNESS	Go	Apache-2.0	yes	yes	yes	Intel

* work in progress.

Source: 2021 IEEE International Conference on Service-Oriented System Engineering (SOSE) | 978-1-6654-3477-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SOSE52839.2021.00019

DAY 5: CLOUD NATIVE 5G 인프라

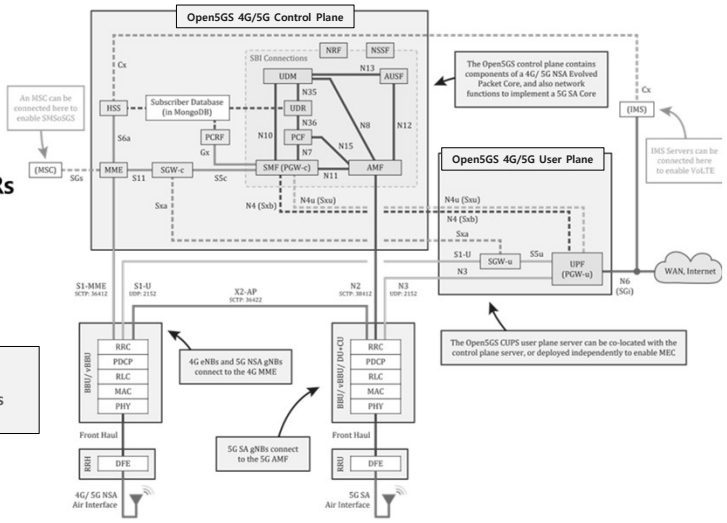
❖ 오픈소스(예): 5G 시험 환경



DAY 5: CLOUD NATIVE 5G 인프라

❖ 오픈소스 응용(예): Open5GS

- Open5GS 4G/5G Control Plane
- Open5GS 4G/5G User Plane
- 호환 상용 5G (gNB)
- 호환 상용 4G (eNB)
- 호환 4G/5G Software Stacks + SDRs
- 호환 gNB @ UERANSIM



- Commercial 5G
- Commercial 4G
- 4G/5G Software Stacks + SDRs
- gNB @ UERANSIM

https://open5gs.org/open5gs/docs/guide/01-quickstart/

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DAY 5: CLOUD NATIVE 5G 인프라

❖ 오픈소스(예): eNodeBs / gNodeBs tested on Open5GS

- **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

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DAY 5: CLOUD NATIVE 5G 인프라

❖ 오픈소스(예): eNodeBs / gNodeBs tested on Open5GS

- **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
  - Ericsson BaseBand 6630 (21Q1 Software)
  - Ericsson RBS 6601 + DUL 20 01 + RUS 01 B8
  - Gemtek WLTGFC-101 (S/W version 2.1.1746.1116)
  - Huawei BTS3900 (S/W version V100R011C10SPC230)
  - Huawei BBU5900 with RRU5304W Band 7 FDD 2600Mhz 40W Version V100R016C10
  - Nokia FW2PC BC28 Flexi Zone G2 Outdoor Micro FDD LTE 700 MHz High Power
  - Nokia FWH1 B38 Flexi Zone Outdoor Micro TD LTE 2600 MHz
  - Nokia FRGY Flexi BTS BBU with Nokia FRCG RRU Band 5 850Mhz FDD 40W. Version 16.1A to 19.0
  - Ruckus Q710 and Q910

https://open5gs.org/open5gs/docs/hardware/01-genodebs/

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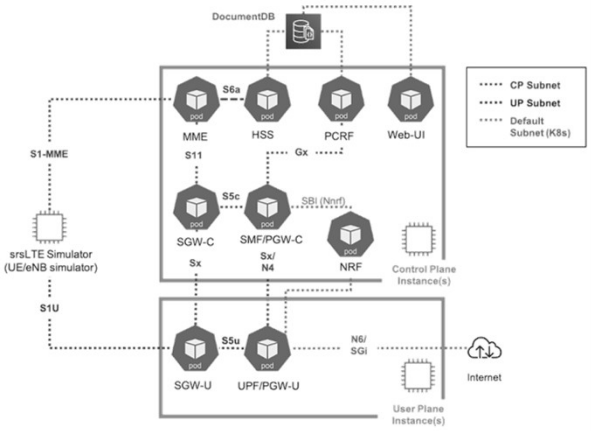
DAY 5: CLOUD NATIVE 5G 인프라

❖ 클라우드 서비스의 모바일 코어 네트워크 (예): 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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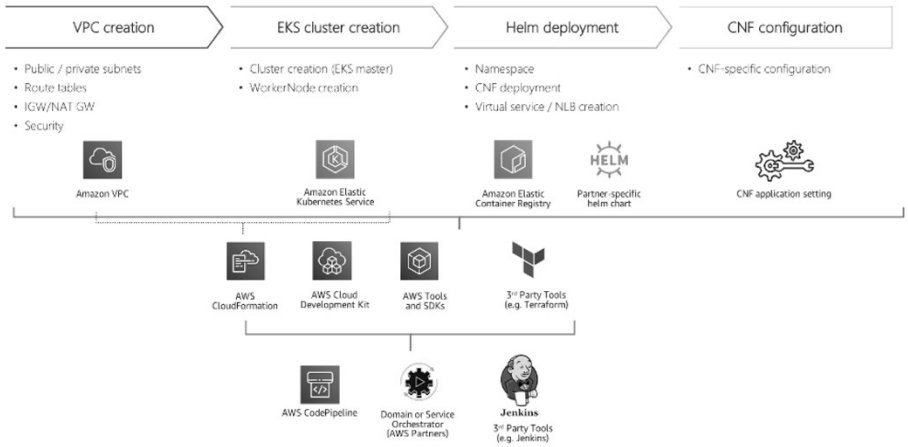
DAY 5: CLOUD NATIVE 5G 인프라

❖ 클라우드 서비스의 모바일 코어 네트워크 (예): Amazon Elastic Kubernetes Service

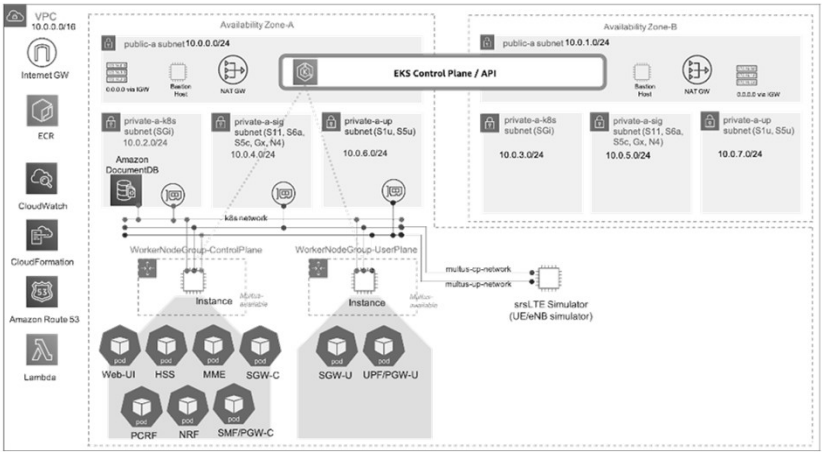


Source: https://aws.amazon.com/blogs/opensource/open-source-mobile-core-network-implementation-on-amazon-elastic-kubernetes-service/

DAY 5: CLOUD NATIVE 5G 인프라

❖ 클라우드 서비스의 모바일 코어 네트워크 (예): 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/

DAY 5: CLOUD NATIVE 5G 인프라

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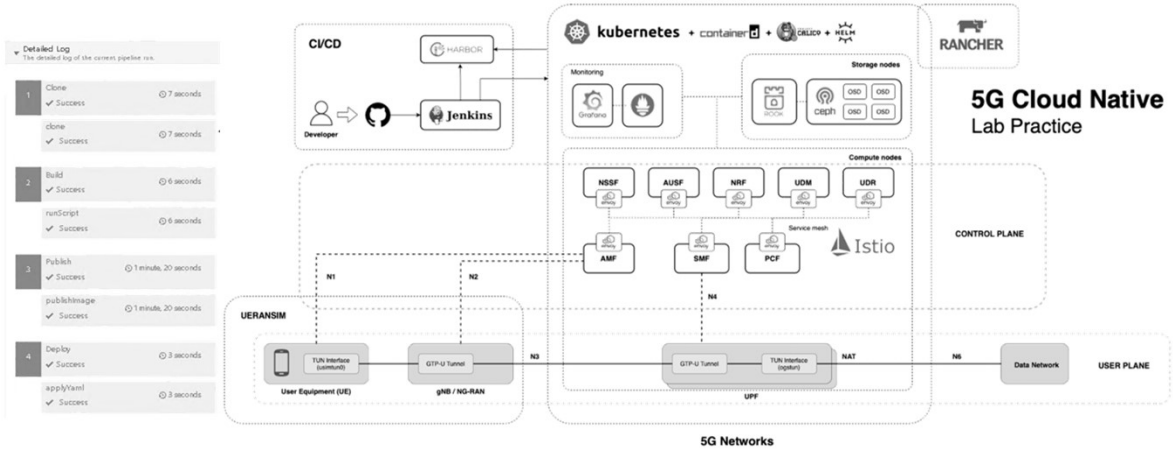
❖ 5G Cloud Native Lab

- Jenkins, Grafana/Prometheus, Harbor, Kubernetes, Calico, Helm, Rook, Ceph, Rancher, Istio



JS Lab

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DAY 5: CLOUD NATIVE 5G 인프라

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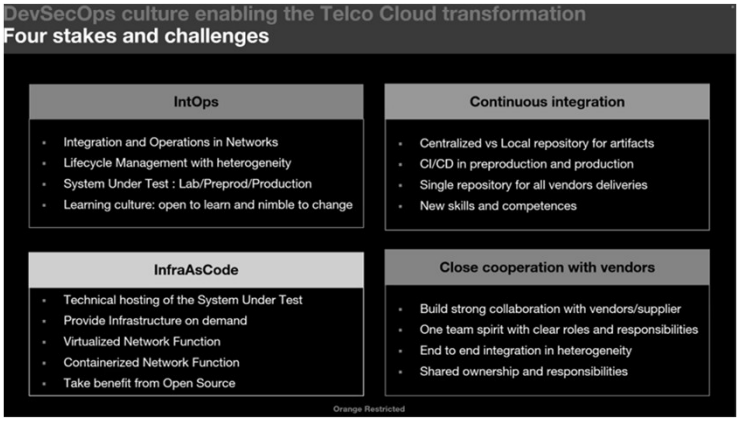
❖ DevSecOps culture enabling the Telco Cloud transformation

- IntOps
- Continuous integration
- InfraAsCode
- Close cooperation with vendors

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



JS Lab

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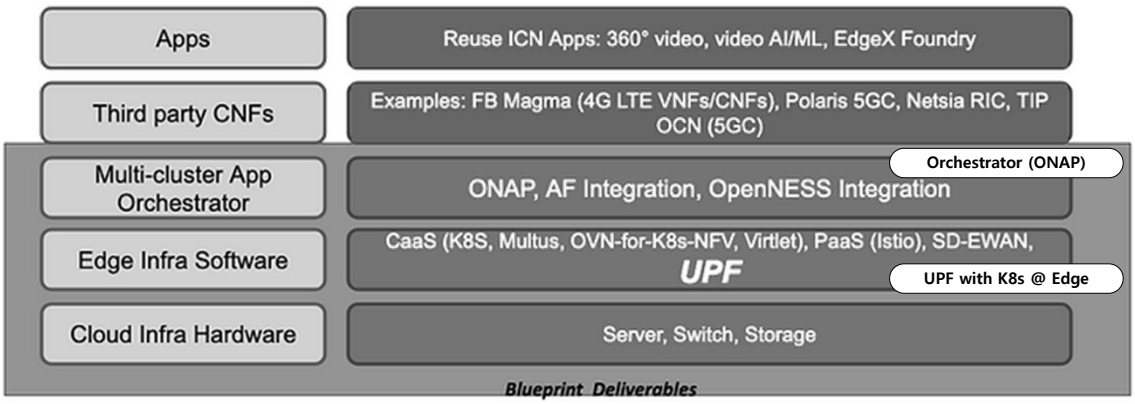
DAY 5: CLOUD NATIVE 5G 인프라

❖ **Private LTE/5G ICN Blueprint Software Stack: NFVI hardware, NFVI software, Orchestrator, Workloads (CNFs), Workloads (CNAs)**



Source: https://www.lfedge.org/2020/06/16/private-lte-5g-icn-akraino-blueprint/

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DAY 5: CLOUD NATIVE 5G 인프라

❖ **Private LTE/5G ICN Blueprint Software Stack**

- **하드웨어(NFVI hardware):** Standard server, switch, storage components
- **소프트웨어(NFVI software):** Kubernetes with OVN (SDN), Virtlet (to run VMs), Multus (for multiple CNI), Istio, and SD-EWAN (to connect an app across clouds). A main component in the NFVI software will also be an open source 5G UPF CNF.
- **오케스트Orchestrator:** ONAP with AF integration, OpenNESS
- **Workloads (CNFs):** Facebook Magma for vEPC, TIP OCN and Polaris for 5GC
- **Workloads (CNAs):** We are starting with the applications in the original ICN blueprint, viz. 360° video, EdgeX Foundry, video AI/ML. However, we might change things around to collaborate with other Akraino blueprints such as the 5G MEC blueprint that is working on cloud gaming, HD video, and live broadcasting.

Source: https://www.lfedge.org/2020/06/16/private-lte-5g-icn-akraino-blueprint/

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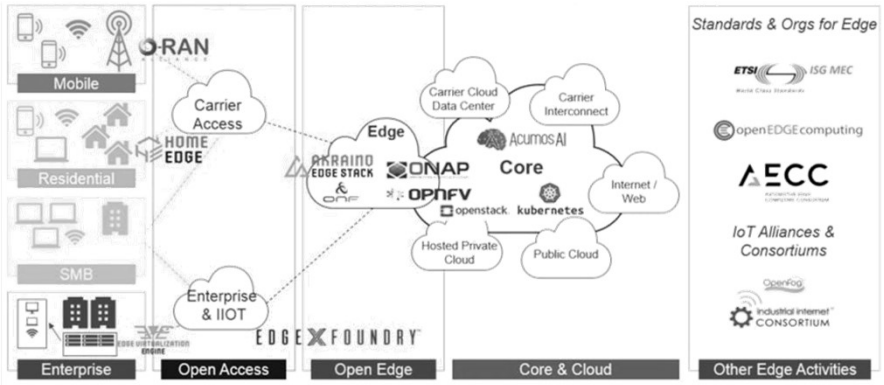
DAY 5: CLOUD NATIVE 5G 인프라

❖ **리눅스 재단의 에지 관련 프로젝트**

- **Standards** (표준)
- **Ref Arch** (레퍼런스 아키텍처)
- **Ref Implementation** (적용 레퍼런스)



THE LINUX FOUNDATION

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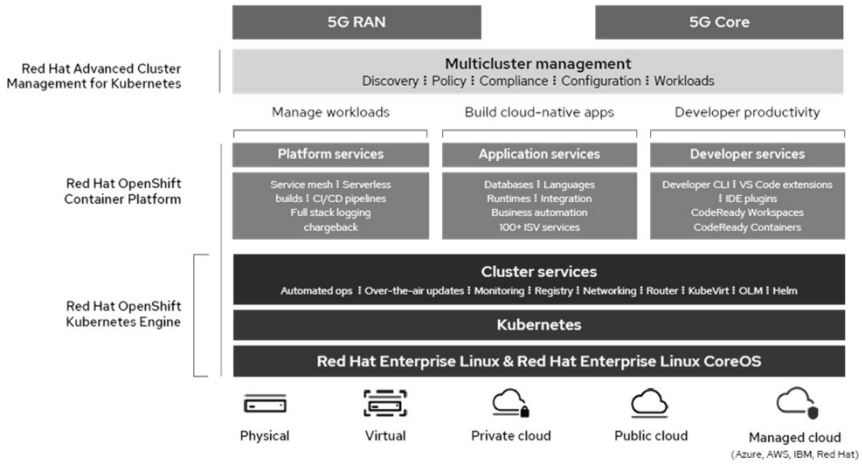
DAY 5: CLOUD NATIVE 5G 인프라

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

Source: Red Hat



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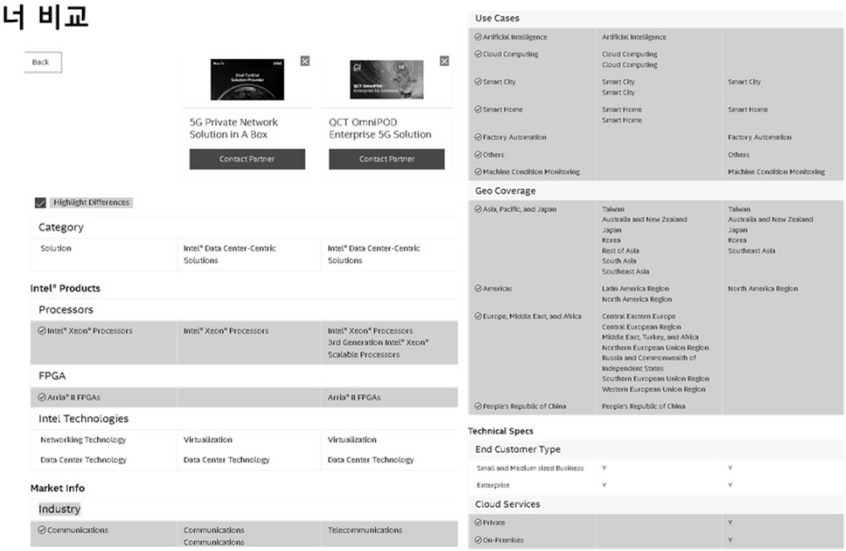
DAY 5: CLOUD NATIVE 5G 인프라

❖ 제조사 (예): Intel 파트너 비교

- 5G in A Box
- QCT



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DAY 5: CLOUD NATIVE 5G 인프라

❖ 텔코(Telco)를 위한 오픈소스 프로젝트 생태계

- 오픈스택 재단 (OpenStack Foundation)
- 리눅스 재단 (Linux Foundation)
  - CNCF (Cloud Native Computing Foundation) Telecom User Group
  - Hyperledger 의 Telecom SIG (https://wiki.hyperledger.org/display/TCSIG/Telecom+SIG)
  - Acumos [LF AI Foundation]
  - OPNFV (Open Platform for NFV)
  - CNTT (Common NFVI Telecommunications Taskforce)
  - Anuket (OPNFV+CNTT) **2021년
  - ONAP (Open Network Automation Platform)
- OCP (Open Compute Project)
- ONF (Open Networking Foundation)
- TOSCA (Topology Orchestration Specification for Cloud Applications) 표준
- Cloudify
- TeraFlow
- Public Cloud의 오픈소스 서비스 (AWS, Azure, ..)

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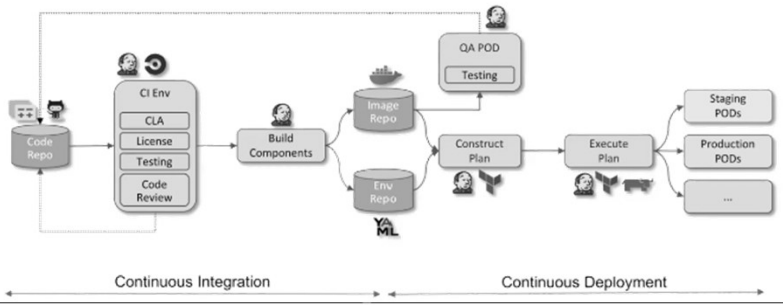
DAY 5: CLOUD NATIVE 5G 인프라

❖ 리눅스재단 (예: Featured LFN for 5G Capabilities)

- ONAP SDN Controller for Radio (SDN-R) based on OpenDaylight
- High-performance, flexible 5G user plane with FD.io and VPP
- 5G Cloud Native Network POC
- O-RAN Software Community for the creation of software for the RAN
- Tungsten Fabric and Akraino for SDN/NFV for 5G and Edge Use Cases
- LF Training Course: Open Source and the 5G Transition



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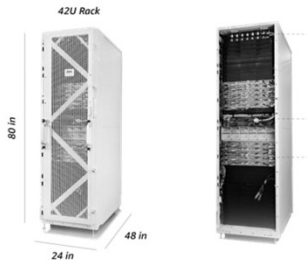
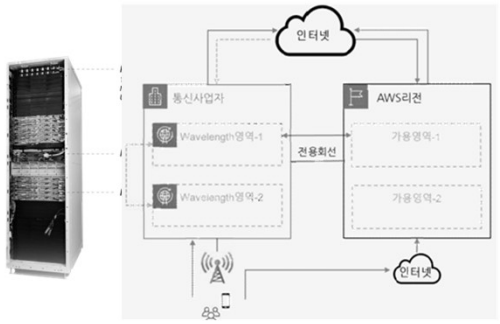
DAY 5: CLOUD NATIVE 5G 인프라

❖ 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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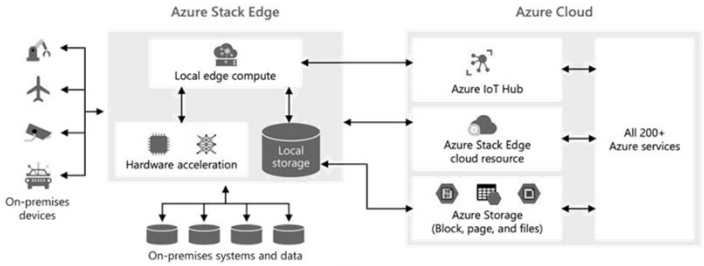
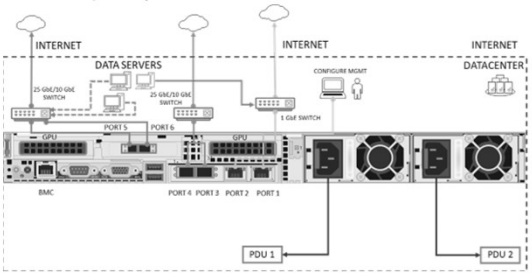
DAY 5: CLOUD NATIVE 5G 인프라

❖ Azure Stack Edge



Microsoft Azure Stack은 하드웨어 어플라이언스 제공 (HCI 포함)



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

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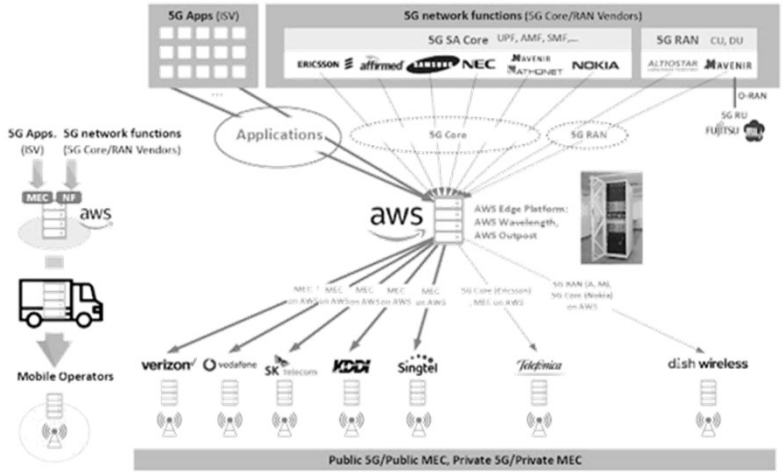
DAY 5: CLOUD NATIVE 5G 인프라

❖ How different operators are planning to use AWS in their Networks.



Source: https://www.telecomsinfrastructure.com/2021/06/aws-for-public-and-private-5g-networks.html

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DAY 5: CLOUD NATIVE 5G 인프라

❖ AWS Private 5G 평가판

Source: https://aws.amazon.com/ko/about-aws/whats-new/2021/11/preview-aws-private-5g/

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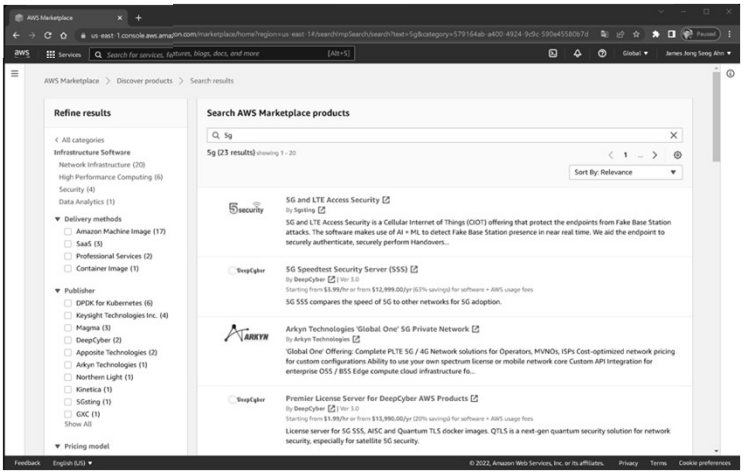
DAY 5: CLOUD NATIVE 5G 인프라

❖ 아마존 AWS 마켓플레이스의 5G Product 제공

- 전체 43개의 서비스 제공
- Infrastructure 제품 20개 제공



Source: https://us-east-1.console.aws.amazon.com/marketplace/home?region=us-east-1#/search!mpSearch/search?text=5g&category=579164ab-a400-4924-9c9c-590e45580b7d

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DAY 5: CLOUD NATIVE 5G 인프라

❖ 마이크로소프트 Azure 프라이빗 5G 코어

Source: https://azure.microsoft.com/ko-kr/services/private-5g-core/#features

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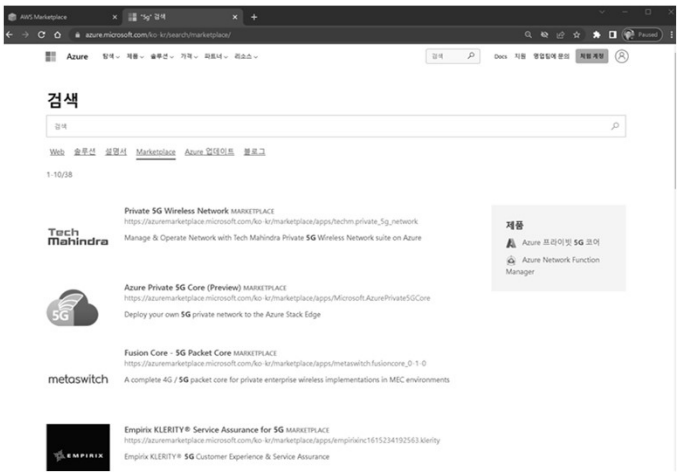
DAY 5: CLOUD NATIVE 5G 인프라

❖ 마이크로소프트 Azure 마켓플레이스의 5G Product 제공

- 전체 38개의 서비스 제공
- Azure 프라이빗 5G 코어



Source: https://azure.microsoft.com/ko-kr/search/marketplace/

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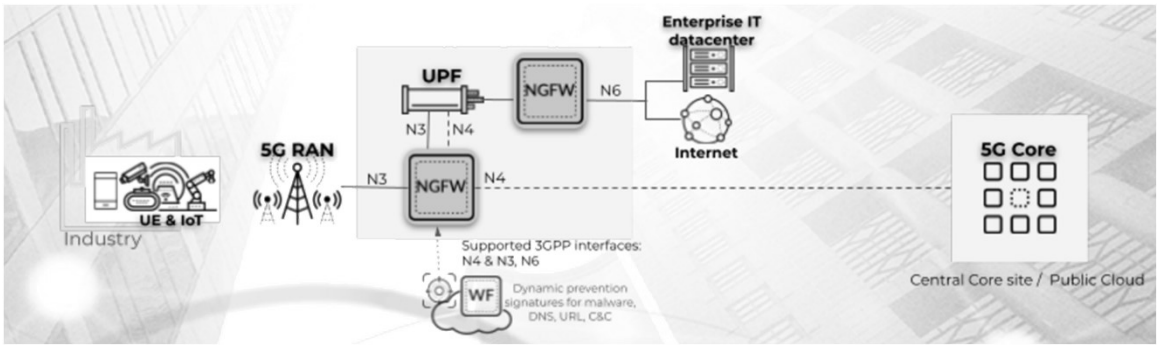
DAY 5: CLOUD NATIVE 5G 인프라

❖ 보안 솔루션 제조사(예): Private 5G

• Deployment Scenario 1 (UPF is on-premises)



Source: Mobile Network Infrastructure Getting Started, Palo Alto

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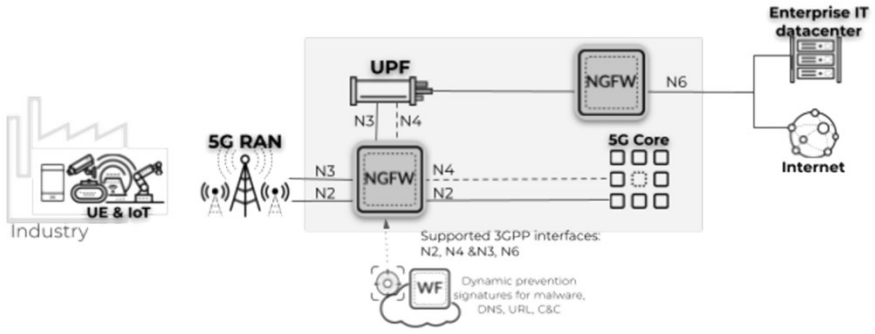
DAY 5: CLOUD NATIVE 5G 인프라

❖ 보안 솔루션 제조사(예): Private 5G

• Deployment Scenario 2 (5G Core including UPF is on-premises)



Source: Mobile Network Infrastructure Getting Started, Palo Alto

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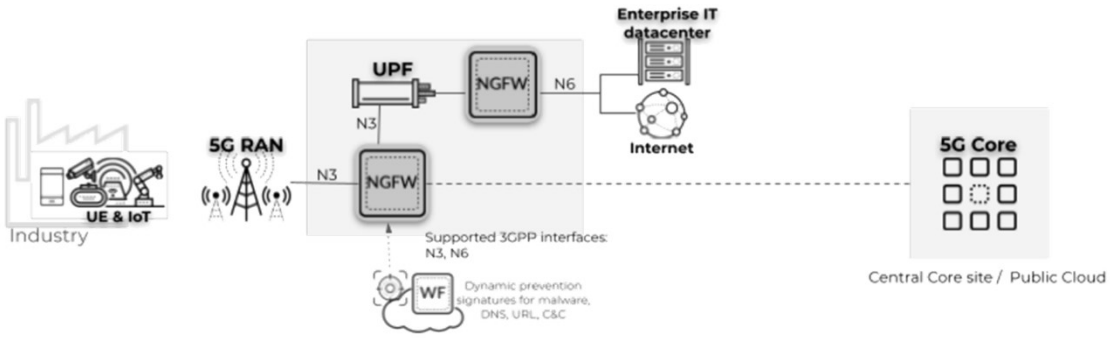
DAY 5: CLOUD NATIVE 5G 인프라

❖ 보안 솔루션 제조사(예): Private 5G

• Deployment Scenario 3 (Only RAN is on-premises)



Source: Mobile Network Infrastructure Getting Started, Palo Alto

DAY 5: CLOUD NATIVE 5G 인프라

❖ KubeVirt Networking

	Calico CNI	OpenStack Neutron
Network Model	Container Networking Model	VPC like Networking Model
Traffic Isolation	Not Support (tenant level)	VLAN, VXLAN, GRE, GENEVE
Provider Network	Not Support	FLAT
Container Network	Support	Not Support
Static IP Address	Not Support	Support
VM & Container Inter-connection	Not Support	Partially Support via Kuryr
Stateful Firewall	Partially Support via Network Policy	Support via Security Group
Load Balancer	Support	Support via Octavia
Acceleration	eBPF	OVS-DPDK, SR-IOV, PCI-PT

DAY 5: CLOUD NATIVE 5G 인프라

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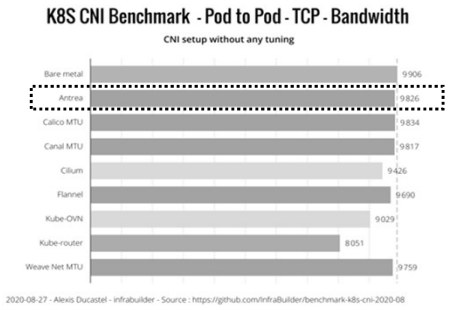
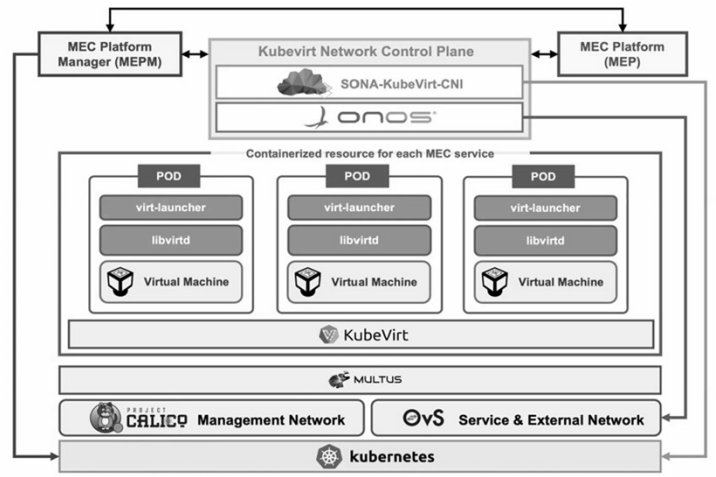
❖ KubeVirt Networking

Antrea extends the benefit of programmable networks from Open vSwitch (OVS) to Kubernetes.





Source: : https://itnext.io/benchmark-results-of-kubernetes-network-plugins-cni-over-10gbit-s-network-updated-august-2020-6e1b757b9e49

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DAY 5: CLOUD NATIVE 5G 인프라

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❖ KubeVirt Networking

CNI Benchmark August 2020 infraBuilder	Config	Performances (bandwidth)				Resources consumption (cpu/ram)					Security features			
	MTU	Pod to Pod		Pod to Service		Idle	Pod to Pod		Pod to Service		Network Policies		Encryption	
	setting	TCP	UDP	TCP	UDP	none	TCP	UDP	TCP	UDP	in	out	activation	Performance
Antrea	auto	Very fast	Very fast	Very fast	Slow	Low	Low	Low	Low	Low	yes	yes	at deploy time	Slow
Calico	manual	Very fast	Very fast	Very fast	Fast	Low	Very low	Very low	Very low	Very low	yes	yes	anytime	Very fast
Canal	manual	Very fast	Very fast	Very fast	Very fast	Low	Very low	Very low	Very low	Very low	yes	yes	no	n/a
Cilium	auto	Fast	Very fast	Very fast	Very fast	High	High	High	High	High	yes	yes	at deploy time	Slow
Flannel	auto	Very fast	Very fast	Very fast	Very fast	Very low	Very low	Very low	Very low	Very low	no	no	no	n/a
Kube-OVN	auto	Fast	Very slow	Fast	Very slow	High	High	High	High	High	yes	yes	no	n/a
Kube-router	none	Slow	Very slow	Slow	Very slow	Low	Very low	Low	Very low	Low	yes	yes	no	n/a
Weave Net	manual	Very fast	Very fast	Very fast	Fast	Very low	Low	Low	Low	Low	yes	yes	at deploy time	Slow

Source: : https://itnext.io/benchmark-results-of-kubernetes-network-plugins-cni-over-10gbit-s-network-updated-august-2020-6e1b757b9e49

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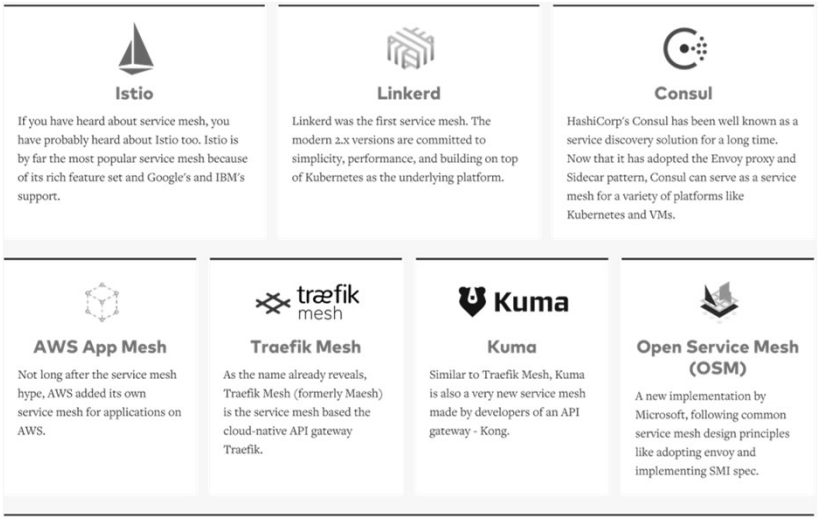
DAY 5: CLOUD NATIVE 5G 인프라

❖ Service Mesh 비교



Source: : https://servicemesh.es/

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DAY 5: CLOUD NATIVE 5G 인프라

❖ Service Mesh 비교

	Istio	Linkerd	AWS App Mesh	Consul	Traefik Mesh (formerly Maesh)	Kuma	Open Service Mesh (OSM)
Supported Protocols							
TCP	yes	yes	yes	yes	yes	yes	yes
HTTP/1.1+	yes	yes	yes	yes	yes	yes	yes
HTTP/2	yes	yes	yes	yes	yes	yes	yes
gRPC	yes	yes	yes	yes	yes	yes	yes
Sidecar / Data Plane							
Automatic Sidecar Injection	yes	yes	yes	yes	yes (per Node)	yes	yes
CNI plugin to avoid pod network priviledges	yes	yes	yes	no	no	yes	no
Platform and Extensibility							
Platform	Kubernetes	Kubernetes	ECS, Fargate, EKS, EC2	ECS (tech preview), Kubernetes, Nomad, VMs (Universal)	Kubernetes	Kubernetes, VMs (Universal)	Kubernetes
Cloud Integrations	Google Cloud, Alibaba Cloud, IBM Cloud	DigitalOcean	AWS	HCP Consul on AWS, Microsoft Azure			Microsoft Azure
Mesh Expansion Extension of the Mesh by containers/VMs outside the cluster	yes	no	yes, within AWS	yes	no	yes	
Multi-Cluster Mesh Control and observe multiple clusters	yes	yes		yes	no	yes	no
Service Mesh Interface Compatibility							

Source: : https://servicemesh.es/

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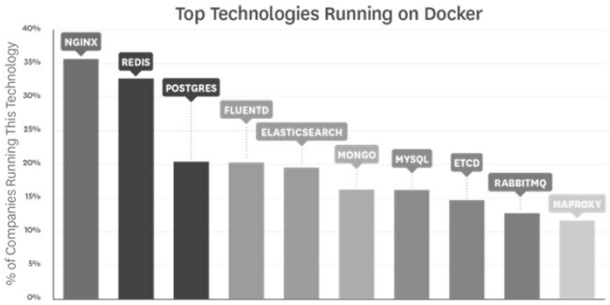
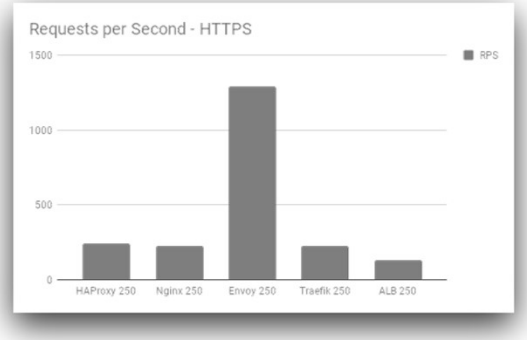
DAY 5: CLOUD NATIVE 5G 인프라

❖ Load balancer





Source: : https://www.loggly.com/blog/benchmarking-5-popular-load-balancers-nginx-haproxy-envoy-traefik-and-alb/
Source: : https://thenewstack.io/why-f5-networks-bought-nginx-containers-and-existing-user-base/

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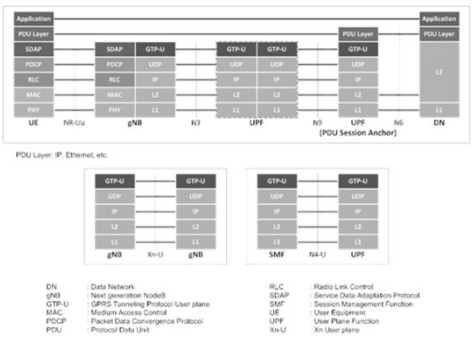
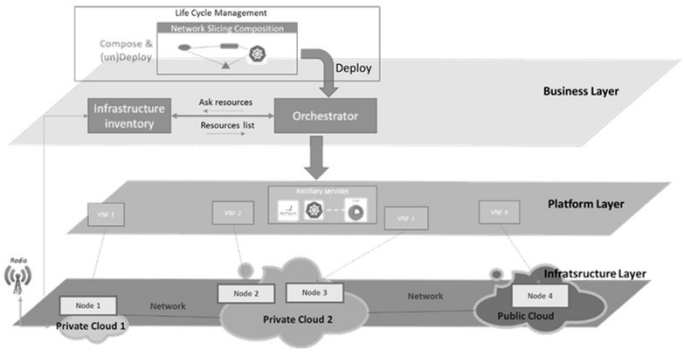
DAY 5: CLOUD NATIVE 5G 인프라

❖ L7 LB

- Platform / Defining all the required APIs/interfaces
- Mapping the different VNFs to the right nodes in the infrastructure layer





Source: : https://sdn.ieee.org/newsletter/january-2018/5g-platform-and-not-protocol

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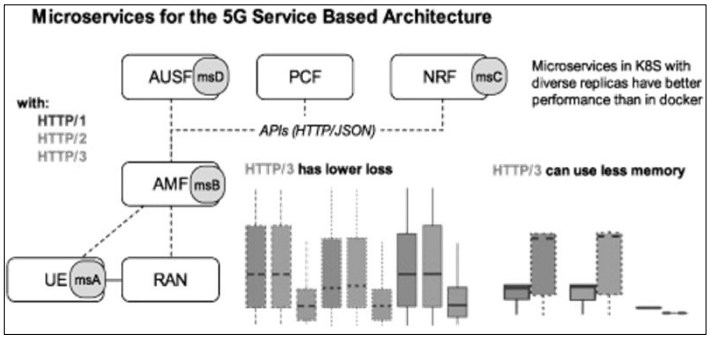
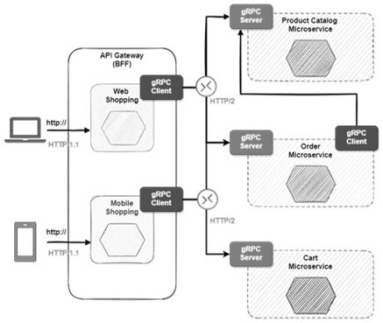
DAY 5: CLOUD NATIVE 5G 인프라

❖ **HTTP/3**





Source: : https://onlinelibrary.wiley.com/doi/abs/10.1002/nem.2132

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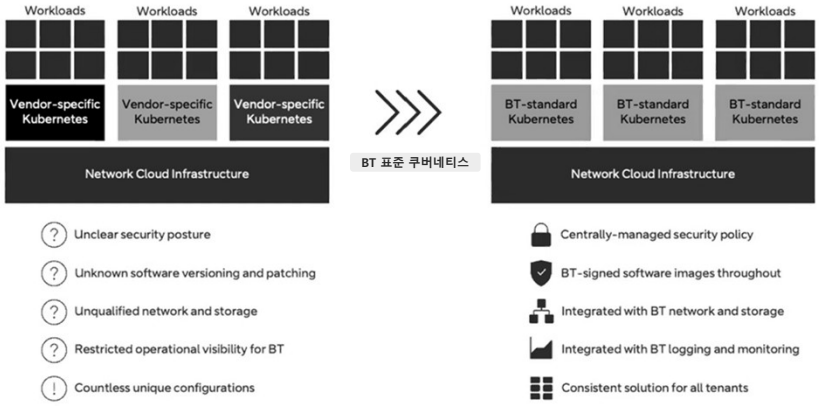
DAY 5: CLOUD NATIVE 5G 인프라

❖ **Containerization at Scale (예): BT**

• **A consistent and observable Kubernetes service for Cloud-native workload**



Source: BT

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DAY 5: CLOUD NATIVE 5G 인프라

❖ Cloud Native 5G 인프라 실습 (별도 교재)

실습 (별도교재)

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