NETWORK BUSINESS QUARTERLY℠

NFV/SDN Telecom Market Landscape

Second Half 2020

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TBR

TECHNOLOGY BUSINESS RESEARCH, INC.

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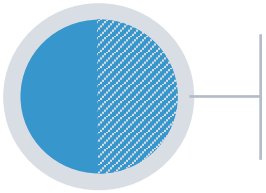
TBR's definition of the telecom NFV/SDN market

TBR's NFV and SDN research encompasses the internal (i.e., network operations) and external (e.g., SD-WAN and other virtual network functions [VNFs] sold to end users such as enterprises) NFV- and SDN-related initiatives of communication service providers (CSPs). Specifically, this includes all initiatives and investments by CSPs pertaining to the following:

- SDN
- VNFs
- NFV infrastructure (NFVI), including data center-related equipment (servers, storage, networking); network hardware that pertains to NFV or SDN but resides outside of a data center environment, such as transport and radio infrastructure for vRAN; and customer premises equipment (CPE), such as universal CPE (uCPE)
- Management and orchestration (MANO), including NFV Orchestration (NFVO), VNF Manager (VNFM) and virtualized infrastructure manager (VIM)

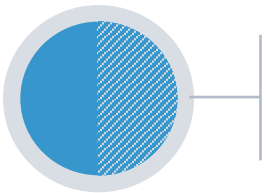
Executive Summary

CSPs begin integrating vRAN and 5G SA infrastructure to reap the benefits offered by virtualization



Open RAN and vRAN deployments will gradually gain traction over the coming decade

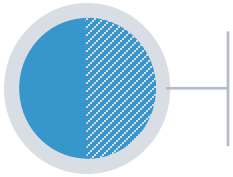
- Open RAN and vRAN trials are accelerating as CSPs seek to realize benefits like capex and opex savings, greater flexibility, reduced vendor lock-in, and the ability to integrate AI and machine learning (ML) capabilities. Commercial deployments will begin to spread in 2021 as some incumbent CSPs, such as Verizon, ramp up and new entrants, such as Dish Network, begin their nationwide deployments in the new architecture.
- Despite growing CSP interest in open RAN and vRAN, most 5G implementations will be in traditional RAN architectures (e.g., D-RAN and C-RAN) through most of the coming decade. A key reason for this is the software upgradability of millions of existing LTE base stations to 5G, which will keep CSPs wedded to the traditional RAN architecture for some time, slowing the pace of open RAN and vRAN adoption. This will cause CSPs to reserve initial vRAN and open RAN rollouts primarily to greenfield builds.
- vRAN and open RAN adoption will also be limited in certain countries, such as the U.S., U.K. and Germany, that lack fiber in the access layer of the network, which is critical to support the anyhaul requirements of the architecture.
- Despite a relatively slow start in the first half of the decade, vRAN and open RAN deployments will gradually accelerate throughout the 2020s as the theoretical cost savings and other benefits, such as increased agility and flexibility, will be too attractive for CSPs to ignore. The success of early adopters, such as Rakuten and Dish Network, will also serve as a catalyst for industry adoption of the technologies.



The race to 5G stand-alone commences, but initial benefits will be limited

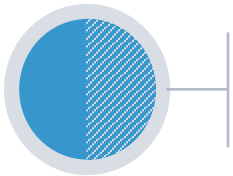
- In August T-Mobile launched the first global 5G stand-alone (SA) network, and operators including AT&T, China Mobile, China Telecom, China Unicom, Dish Network and Verizon have either begun to implement 5G SA or plan to do so by the end of 2020.
- Expanded range of coverage is a key initial benefit realized from 5G SA, exemplified by T-Mobile's 5G SA network enabling the operator to expand its 600MHz 5G coverage range by 30%. T-Mobile also tested a 40% reduction in latency over its 5G SA network. 5G SA will provide CSPs other benefits including faster download and upload speeds as well as improved device battery life.
- Though 5G SA will provide the aforementioned benefits, monetization of 5G-related use cases over the next few years will be gradual as the bulk of use cases requiring the ultra-low latency provided by 5G SA are still in development. Integrating a virtualized 5G core network will also provide CSPs the opportunity to monetize 5G SA by selling network slices to enterprises and other customers to optimize connectivity for specific use cases.

The pool of vendors capable of aiding telecom operators in their network transformations is growing



Japan's vendors reassert themselves on the global stage

- Japan-based vendors have renewed momentum due to their embrace of open and/or virtualized networking solutions. Until recently, vendors such as NEC and Fujitsu were losing market share and mindshare to Western-based and China-based vendors and were increasingly confined to supplying CSPs in their domestic market, while shrinking internationally due partially to a perceived lack of innovation. In 2020, however, NEC and Fujitsu have been making the shortlists of CSPs, including Vodafone, as potential vendors for their network transformations. In the most high-profile win, Fujitsu was selected by Dish Network to provide the radio units for the operator's greenfield 5G network leveraging open vRAN.
- NEC and Fujitsu can in part thank Rakuten and its and its greenfield approach to building out a virtualized network across Japan for the increased awareness of and confidence in Japan-based vendor solutions. While both vendors took part in Rakuten's virtual LTE network build, NEC has emerged as one of Rakuten's key suppliers for its 5G network. NEC is providing the SA core for Rakuten, and the two companies will market that solution globally.

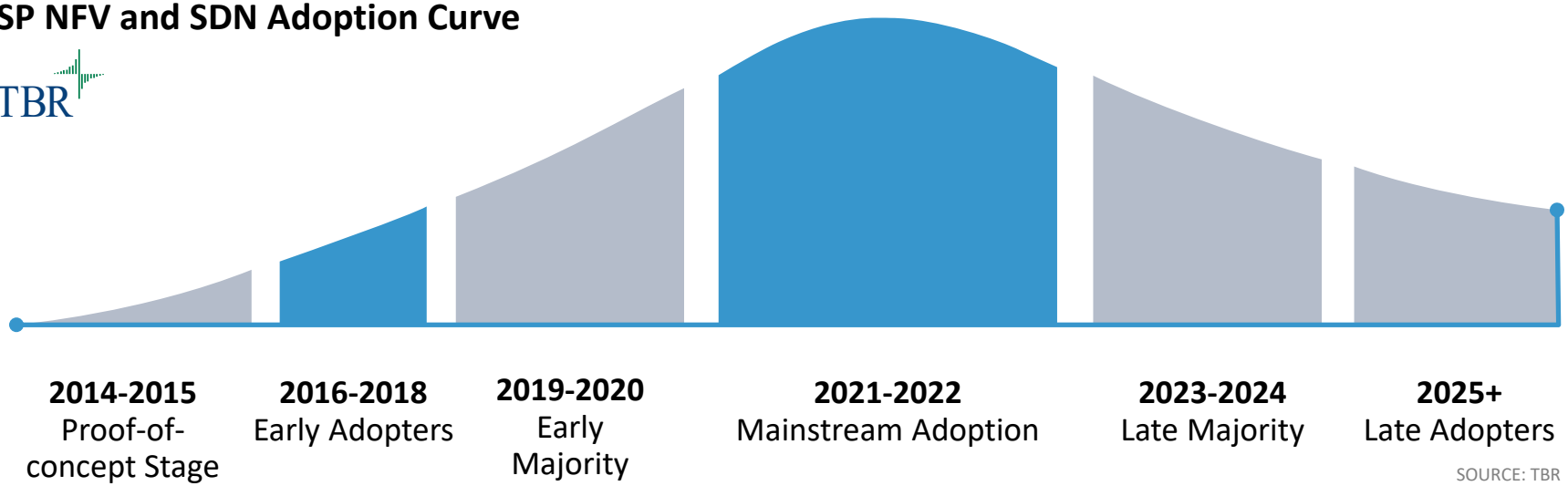


Google's and Microsoft's cloud businesses aim to win operators with the proverbial carrot, while AWS chooses the stick

- Google Cloud and Microsoft are leading in terms of virtualized and containerized go-to-market strategies in the telecom space. Google's Anthos for Telecom is a Kubernetes-based container platform, which will enable operators to run their OSS, BSS and network functions in the cloud. Microsoft is taking a three-stage approach that starts with migrating operators' packet core and voice workloads onto Azure through virtual machines (VMs), then containerizing network functions once they are virtualized on Azure. Containerized IT environments are desirable because they enable customers to move data across clouds and on premises. In on-premises scenarios, Google and Microsoft will focus on deployments in operator-owned data centers. However, Microsoft aims to increase its stickiness by running operator workloads on Azure Edge Zones, which works in tandem with Affirmed Networks' 5G core, as well as Azure AI and ML solutions.
- Amazon Web Services (AWS) will focus on migrating operators to its public cloud and Wavelength edge infrastructure, as well as its proprietary operating system (OS) to lock in customers. This mirrors AWS' enterprise strategy, which largely omits open-source technologies from customer engagements when possible. TBR believes AWS' lack of support for open-source software may hinder the company's success in the telecom space.

Operators will increasingly invest in virtualized network solutions, including vRAN and virtual network cores, to reap the full benefits of 5G

CSP NFV and SDN Adoption Curve



SOURCE: TBR

Note: Assumes comprehensive network transformation through NFV and SDN architecture across multiple network domains.

2019-2020 Early Majority

Leading operators will accelerate and broaden their network transformations en route to deploying 5G and becoming digital service providers (DSPs). Softwarization, virtualization, cloudification and automation are foundational aspects of a DSP's network.

Rakuten became the first fully virtualized DSP when it launched its mobile network in April, and Dish Network is following Rakuten's model. Should these companies' approach to network architecture work, it will embolden other CSPs to double down on their network transformations and hasten their migration to white-box hardware and cloud-native architectures.

2021 and Beyond

5G SA network build-outs will expand the scope of CSP network transformations, and vRAN will become commercialized at scale. CSPs that want to participate in the 5G ecosystem will need to upgrade their mobile core from an evolved packet core (EPC) to a 5G core so they can support new use cases of the network, such as network slicing and edge computing. Adopting a cloud-native 5G core is ideal and ultimately what CSPs need to do to remain viable.

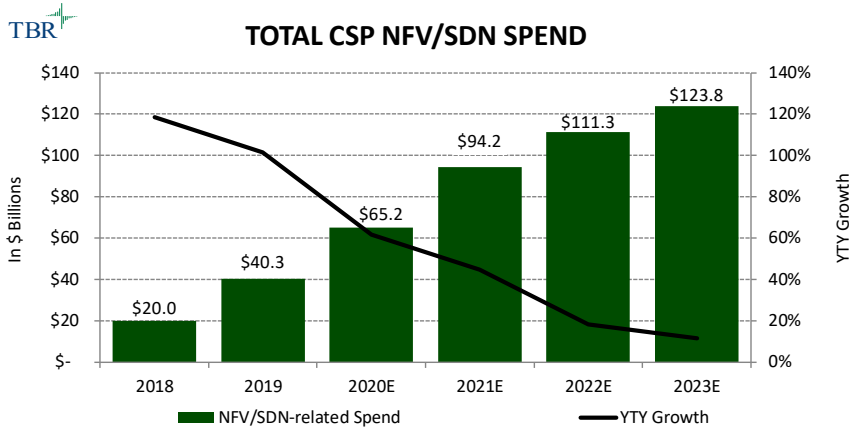
Leading CSPs will evolve from using VMs and containers to leveraging cloud-native VNFs and advanced MANO platforms. By 2025 early adopters will begin to achieve their end-state goal of becoming virtual network operators.

Leading operators will migrate to a cloud-native architecture over the next 5 years to support their transformation into digital service providers

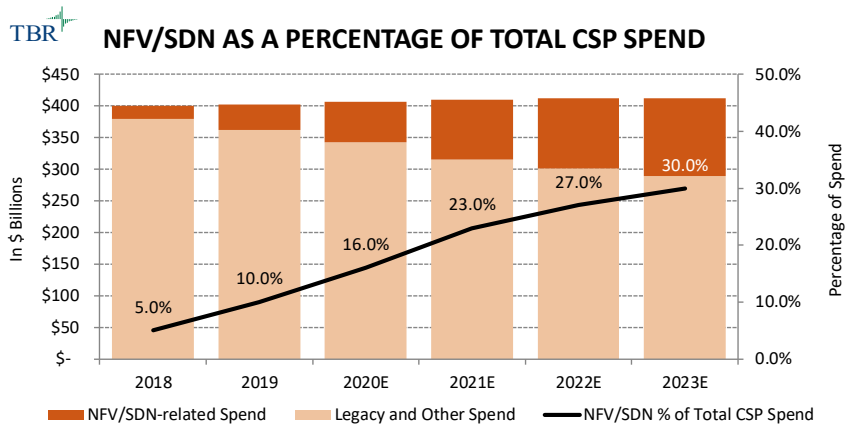
The marathon to full network virtualization: From humble beginnings to end-state utopia

Phase 1: Virtual Machines (2013-2017)	Phase 2: Containers (2018-2021)	Phase 3: Cloud-native/Microservices (2022 and Beyond)
Key Domains: SD-WAN, firewalls, unified threat management, EPC, IP Multimedia Subsystem (IMS), content delivery network (CDN), uCPE	**Key Domains:** MANO, routers, switches, optical transport, Converged Cable Access Platform (CCAP), Optical Line Terminal (OLT), set-top boxes	**Key Domains:** RAN, fixed access, 5G Core, OSS, BSS
• CSPs prioritized virtualizing network domains that provided the greatest ROI, such as IMS and mobile core. • Most NFV/SDN implementations were hybrid in nature (virtual machines) and tethered to proprietary hardware. Incumbent OEMs resisted CSP pressure for white boxes, and proprietary boxes won out because the white-box ecosystem was too immature to support carrier-grade requirements. • SD-WAN drove significant interest in NFV/SDN as a foundational platform for enterprise digitalization. • By the end of this phase, incumbent vendors became serious about having an NFV/SDN play to stay relevant as the market changes.	• Key open-source consortiums reach critical mass, and conditions become favorable for CSPs to scale NFV/SDN in their networks. • Leading CSPs migrate to Docker, Kubernetes and other container-based platforms to glean further benefits from an evolved network architecture. • White-box hardware (predominantly for use in NFVI) is legitimized and widely deployed in leading CSPs' networks. • MANO platforms become usable at scale. • The COVID-19 pandemic spurs heightened demand for virtualized network solutions to support shifting network demands, such as from the influx of remote workers and learners.	• A significant portion of leading CSPs' networks will be cloud-native by the mid-2020s. • Cloud-native is the end-state goal for CSPs because this architecture provides the full benefits of utilizing a software-mediated and autonomous network. • As MANO evolves, it will have AI, ML and automation deeply embedded and will support cross-domain orchestration. • The first virtual network operators will emerge, and leading CSPs will become true digital service providers. • Networks will be highly distributed at the edge and will interface seamlessly with the core network.

NFV/SDN spend will increase through 2023 as leading CSPs broaden transformation initiatives and new operators build next-gen networks



SOURCE: TBR ESTIMATES



SOURCE: TBR ESTIMATES

Note: CSP spend includes capex and external opex. External opex represents spend that is addressable to vendors. Opex that CSPs use internally is not included in the forecast data.

Key Takeaways

- NFV/SDN spend will increase at a CAGR of 44% to $124 billion between 2018 and 2023, compared to nearly flat overall CSP spend (capex plus external opex) for the global market.
- NFV/SDN spend will scale through the forecast period as leading CSPs broaden their transformation initiatives and as additional CSPs begin their transformational journeys. 5G will be a key catalyst that will push more CSPs to adopt and broaden their NFV- and SDN-related initiatives.
- COVID-19 will serve as a catalyst for digital transformation, which implicates NFV and SDN, as operators will increase investment in the technologies to improve network cost efficiencies long term and support shifting data usage trends arising from the increased number of work-from-home employees and remote learners.
- Rakuten, along with China- and U.S.-based CSPs, will be key drivers of the spend increase in the early years of the forecast.
- TBR expects lower-tier CSPs in developed countries and key CSPs in emerging markets will ramp up NFV/SDN spend in the later years of the forecast period, driving continued spend growth in the overall market.
- Most CSP spend on NFV/SDN to date has been on virtual machines, but this will increasingly transition to container-based and cloud-native, microservices-based spend through the forecast period as CSPs continue their evolutionary journeys.

The Open Networking Foundation begins developing open RAN solutions, joining existing groups such as the O-RAN Alliance and TIP

Key NFV/SDN-related Open-source Organizations/Projects

Category	Organizations/Projects
Central Office	Central Office Re-architected as a Datacenter (CORD), Virtual OLT (vOLT) Hardware Abstraction (VOLTHA)
Containers	CoreDNS, Docker, Istio, Kubernetes, OpenStack, Airship, OpenShift
Hardware	DANOS, OCP, Open19, Open Platform for NFV (OPNFV), TIP
MANO	Open Networking Automation Platform (ONAP), OpenStack, OPNFV, OSM
SDN	ONOS, OpenDaylight, OpenFlow, Tungsten Fabric
vRAN	Open Networking Foundation (ONF), Open vRAN, O-RAN Alliance, TIP (OpenRAN), Open RAN Policy Coalition

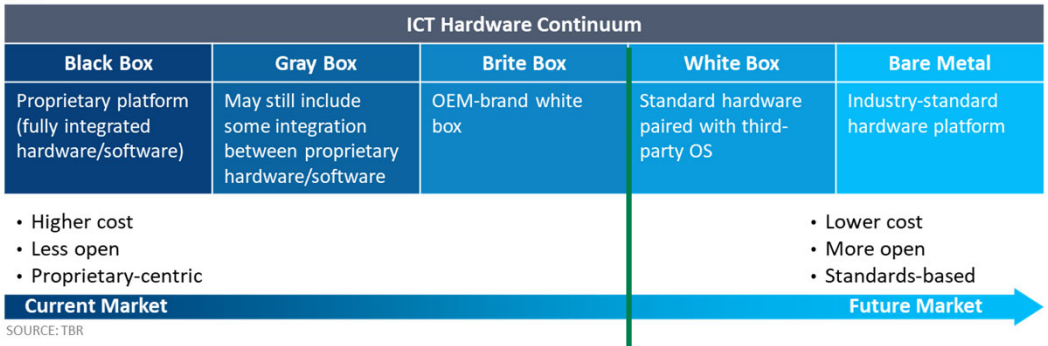
SOURCE: TBR

Note: Open-source category and organizations/projects list are not comprehensive. TBR listed what it deems to be the most important open-source initiatives in the ecosystem.

- Industry consortiums are spearheading and driving open infrastructure initiatives, a key feature of which includes creating standardized, modularized and low-cost (commoditized) hardware that is optimized to be used in data center and network environments.
- There is a sustained movement among CSPs to commercialize open infrastructure and migrate network functions from purpose-built appliances to function-agnostic data centers. The primary reason CSPs want open infrastructure is the significant cost savings and flexibility these solutions provide compared to proprietary "closed" systems. The physical network will become standardized and composable over time. The closest glimpse of this can be seen today in webscales' central data centers, which use commodity ICT gear that is automated and expendable when it fails.

- There has been significant open-source-related activity regarding open RAN and vRAN as CSPs aim to disrupt this space since RAN is the most expensive domain in network construction and has historically been proprietary with a high degree of vendor lock-in. For instance, the ONF announced its SD-RAN project in August, which is focused on developing open-source and multivendor solutions to support LTE and 5G RAN deployments. As part of the project, the consortium will develop an open-source Near Real-Time RAN Intelligent Controller that is interoperable with open RAN architecture.

AT&T furthers its leadership in white-box development by creating a new open core routing platform with Broadcom, DriveNets and UfiSpace



Key Black- and Gray-box Vendors (OEM)

Ciena
Cisco
Dell Technologies
Ericsson
Fujitsu
Hewlett Packard Enterprise (HPE)
Huawei
Juniper Networks
Lenovo
NEC
Nokia
ZTE

Key White-box Vendors (ODM)

Accton (owns Edgecore)
Advantech
Celestica
Compal Electronics
Delta Networks
Inspur
Lanner Electronics
New Kinpo Group
Penguin Computing
Quanta Cloud Technology
UfiSpace
Wistron
Wiwynn

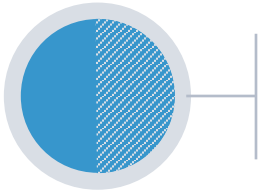
Note: Vendor lists are not comprehensive.

Key Takeaways

- White boxes are becoming a key feature of leading CSPs' road maps as they seek to defray the infrastructure cost to deploy new technologies into their networks. With webscales first showing the way, AT&T, Verizon, Telefonica and Vodafone are key telcos leading the charge toward white boxes, and other telcos and cablecos are expected to follow suit as the market for white boxes matures. These CSPs will increasingly procure white-box ICT gear directly from ODMs. TBR's research suggests ODM gear is up to 50% less costly than OEM gear and is also lower from a TCO perspective.
- AT&T is leading the way among its CSP peers in terms of white-box adoption as the company is in the process of deploying over 60,000 white-box routers and is spearheading an industry initiative to develop an open-source-based operating system (or disaggregated network operating system [DANOS]) to operate white boxes in a network environment.
- AT&T furthered its network transformation initiatives by announcing in September it has deployed a next-generation open disaggregated core routing platform in collaboration with Broadcom, DriveNets and UfiSpace. The solution integrates DriveNets' Network Cloud routing software, Broadcom's Jericho2 chips and white-box hardware developed by UfiSpace.

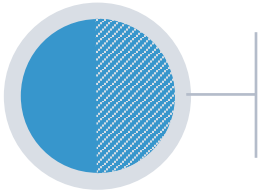
Operator Adoption Trends

Operators face disruption in the enterprise market as webscales advance their intelligent network portfolios



Webscales will dilute operators' role in the edge by providing the 'intelligent network' to enterprises

- AWS, Google and Microsoft intend to provide full-stack, intelligent network solutions to enterprises to drive digital transformation, evidenced by Microsoft's recent announcement of Azure for Operators.
- Webscales view connectivity and ICT hardware as commodities, and they have a cultural philosophy that all the value resides in the software layer and digital platform. This mindset influences webscales' approach to the new distributed computing architecture and will increasingly marginalize operators over time as webscales increase their dominance over the intelligence (core network, MANO, AI, ML), cloud and network domains.
- These solutions will dilute the relationships operators and vendors have with their end customers as webscales will, in most cases, push their "dumb box" agendas, tightly integrated with their software platforms. In these situations, the webscale will provide the intelligence platform, cloud and ecosystem, and the operator, in most cases, will only provide the last-mile connectivity and/or access to their network sites.
- This model also negatively implicates OEMs because in most cases webscales will push their custom-engineered white boxes (e.g., AWS Outposts or Google Anthos) versus having to provide higher-cost OEM hardware, though some enterprises will opt to stick with incumbent hardware providers.



Global CSPs are embracing open RAN, though some operators are taking a wait-and-see approach toward the technology

- Global operators including AT&T, Bharti Airtel, Dish Network, Orange, Rakuten, Reliance Jio, Telefonica, Verizon and Vodafone are advancing their open RAN strategies as they seek to realize benefits including cost savings, greater flexibility and scalability, and the ability to integrate advanced technologies such as AI and ML for automation and performance enhancement. Open RAN adoption is also being spurred by geopolitical pressure, including mandates that networks be "clean" of Huawei and ZTE infrastructure as open RAN will enable operators to accelerate rip-and-replace deployments.
- Some operators, such as BT and T-Mobile, will delay open RAN implementation until the technology has become more mature. For instance, T-Mobile will continue to rely on traditional RAN deployments in the short term to reduce complexity as it aims to meet to its Sprint network integration timeline.
- Operators also have reservations about open RAN in areas such as implementation complexities, security uncertainties and the technology's ability to reliably support highly dense urban markets.

China and the U.S. are early 5G SA adopters as CSPs seek to capitalize on the advanced network and services capabilities enabled by the technology

Americas

- In August T-Mobile launched the first global 5G SA network with suppliers Nokia and Cisco. Transitioning to 5G SA enabled T-Mobile to expand its 600MHz 5G coverage range by 30%, which is providing the operator a time-to-market advantage in launching 5G services in rural markets. AT&T and Verizon will begin deploying 5G SA by the end of 2020 and will expand commercial deployments in 2021.
- Though cable providers have trailed telecom operators in migrating their internal network operations to NFV and SDN, U.S. cablecos have begun prioritizing virtual network services to complement core portfolio segments and support demand for solutions such as SD-WAN and uCPE.

EMEA

- Tier 1 CSPs in EMEA, including Telefonica, DT, Vodafone, BT, Orange, Telecom Italia, Etisalat and VEON, are driving the bulk of spend on NFV and SDN in the region. However, there is also a subset of Tier 2 CSPs, such as Swisscom, Telia and Telenor, that are aggressively deploying NFV and SDN.
- Vodafone ranks as a leader in network transformation in the region as the operator seeks to deploy open RAN technology across its European footprint. In collaboration with Mavenir, Vodafone activated the first LTE open RAN site in the U.K. in August, located in Powys, Wales. Telefonica is also advancing its open RAN strategy and expects up to half of its RAN investments between 2022 and 2025 will be open RAN.

APAC

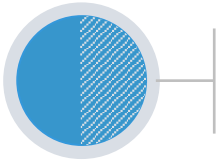
- The build-out of 5G SA networks will advance the integration of NFV/SDN technologies in China as China Mobile, China Telecom and China Unicom have awarded 5G core contracts covering areas including network slicing, cloud unified data management and microservices. For instance, China Mobile is accelerating the construction of its 5G SA core to launch commercial 5G SA services in 2H20.
- India is in the early stages of open RAN integration as operators have begun working with equipment vendors, such as Bharti Airtel with Altiostar and Vodafone Idea with Mavenir, to deploy the technology. Reliance Jio plans to deploy 5G services on in-house infrastructure developed by parent company Jio Platforms once new spectrum becomes available in India. The development will also enable Jio Platforms to offer its 5G infrastructure, which is expected to include an open RAN solution, to other global CSPs.

Dish Network leverages cloud-native solutions from multiple vendors to build its disruptive network

TBR Assessment of CSPs' Network Transformation Initiatives

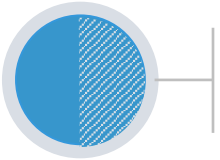
Strategy

- CSPs are investing in NFV and SDN as these network transformations are critical for them to remain relevant and competitive in the digital era and support new services in 5G, IoT and edge computing.
- CSPs are focused on transitioning domains that are relatively easy to virtualize first, such as the mobile core and IMS, while more challenging domains, such as the radio access layer and fixed access, will be among the last domains to be virtualized.
- To increase their capabilities in NFV and SDN, CSPs are targeting hires with relevant skill sets, retraining employees and launching internal startups to quickly enhance resource pools.



Dish Network advances network strategy

- Following the selection of Mavenir as an OpenRAN software provider in April, Dish Network recently announced it will be leveraging solutions from vendors including Altiostar, Blue Planet (Ciena), Fujitsu, Matrixx Software, Nokia, Tucows and VMware. The cost savings gained from virtualized infrastructure and automation will position Dish Network to provide more aggressive pricing to attract customers.
- Leveraging Matrixx Software's converged charging system will enable Dish Network to sell network slices to enterprises and other commercial customers to optimize connectivity for specific use cases. Matrixx's solutions will also enable Dish Network to support dynamic pricing, which leverages AI and automation to continually adjust service pricing based on usage demands, allowing Dish Network to more closely tailor pricing to demands of enterprises and industries.



Network transformation yields cost savings for CSPs

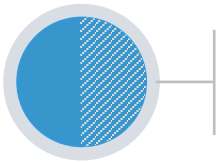
- In September AT&T announced it reached its goal set in 2014 to virtualize 75% of its core network functions by the end of 2020. AT&T's network virtualization initiatives have helped to reduce network operations costs by about 10% in the past year and about 6% for the preceding five years.
- AT&T's network virtualization initiatives are enabling the operator to more effectively support rising traffic demands arising from the pandemic. For instance, the virtualization of Voice over Wi-Fi services has helped AT&T support increased Wi-Fi calling traffic, which has grown by an average of 90% compared to pre-pandemic levels. The transitioning of text messaging traffic from legacy infrastructure to cloud-based infrastructure has also added over 60% capacity to AT&T's messaging platform.

Operators are developing uCPE and vCPE solutions to provide customer benefits including cost savings and reduced floor space occupancy

TBR Assessment of CSPs' Virtual Network Services Strategies

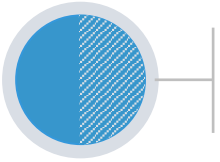
Strategy

- CSPs are expanding the global availability of their SD-WAN portfolios by allying with professional services providers and wholesale partners as well as working with other CSPs to provide last-mile broadband connectivity.
- CSPs have begun developing intercarrier solutions that will provide global customers greater flexibility and service quality by limiting the need to incorporate solutions from multiple vendors with nonintegrated systems.
- CSPs are offering hybrid SD-WAN platforms to accommodate existing multiprotocol label switching (MPLS) customers and to enable businesses to deploy the optimal connectivity options for branch locations.



Comcast Business to launch vCPE platform in 2H20

- Operators are developing uCPE and vCPE (virtual CPE) platforms to provide benefits including reducing the amount of devices needed to be deployed at business sites as well as lowering infrastructure costs in areas including installation, maintenance and support services.
- Comcast Business plans on launching a vCPE platform before the end of 2020, which will position the company to more effectively support the influx of new remote workers. For instance, Comcast Business is developing a SD-WAN service designed for remote employees that may potentially integrate the vCPE platform.



Lumen deepens partnership with VMware

- In September Lumen Technologies (formerly CenturyLink) announced it is expanding its existing partnership with VMware to more deeply collaborate in areas including edge computing, networking and security. The companies will focus on enabling data to be processed closer to customer locations to support business applications requiring ultra-low latency.
- As part of the collaboration, Lumen will integrate VMware SD-WAN by VeloCloud and VMware SASE Platform security architecture to provide a Work from Anywhere solution to support thin-branch applications for businesses of all sizes. The platform will help Lumen spur customer wins as TBR anticipates remote work environments will remain prevalent after the pandemic abates as businesses seek to reap benefits such as greater flexibility and reduced facility costs.

Vendor Assessment

VMware links vendor- and operator-owned data centers via containers

Rakuten and Jio Platforms increasingly position themselves as vendors

- Rakuten and Jio Platforms, the parent of Reliance Jio, increasingly resemble telecom vendors. Rakuten is taking its learnings and technology stack from the greenfield Rakuten Mobile deployment and packaging them together to form the Rakuten Communications Platform. Rakuten Mobile has demonstrated the commercial viability of its network, despite delays caused in part by complex integration work, and the company is betting that any operator interested in its Rakuten Communications Platform (RCP) will prefer to leverage vendors involved with the Rakuten build. This has led Rakuten to invest in several of its suppliers, including acquiring MANO provider Innoeye and taking a majority stake in Altiostar.
- Jio Platforms is actively looking to make acquisitions to help it produce 5G network equipment. The company's 5G vendor journey began in 2018 when it acquired Radisys, but its ambitions are growing as India adopts a "self-reliance" posture to encourage domestic manufacturing and technology development. TBR expects Jio Platforms to acquire at least one India-based 5G-related vendor and leverage its recent influx of cash from U.S.-based companies to develop its technology and ramp up production.
- TBR is skeptical of Rakuten's and Jio Platforms' ability to sell their solutions to fellow CSPs at scale. Most obviously, their domestic competitors will not want to support a rival, but even international CSPs will be hesitant to adopt the barely-proven technology from unestablished vendors.

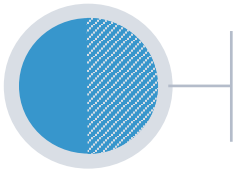
VMware centralizes its telecom-oriented solutions into one offering with Telco Cloud Platform

VMware unified its telecom-oriented offerings in August through VMware Telco Cloud Platform, which combines the vendor's Telco Cloud Infrastructure NFV platform and Telco Automation Cloud for orchestration and automation. In addition, the new offering includes VMware's Tanzu Kubernetes Grid for building, managing and operating containerized workloads in hybrid IT environments. This enables customers to run VMware's Telco Cloud Platform and tools on their existing on-premises IT infrastructure, as well as on VMware's hosted public and private cloud environments. VMware is aligned with CSP road maps and is capturing new CSP customers as these clients increasingly demand cloud-native or containerized functions and move away from VMs. In July Dish Network selected VMware for its Telco Cloud solution, which will run functions from various vendors, including Altiostar and Mavenir, in containers leveraging Kubernetes.

Distributed computing requires programmable, adaptable transport grid

Optical vendors, such as Ciena and Nokia, aim to capitalize on the needs being placed on the transport grid to support distributed computing, whereby routes will need to be flexible and programmable to dynamically align with traffic demand in real time versus the traditional architecture of static, dedicated pipes that serve a singular role. Referred to as anyhaul or xHaul, baking this flexibility into the transport grid is foundational to cost-effectively supporting the low-latency requirements of edge use cases, especially for vRAN.

Incumbent vendors are slowly incorporating cloud-native technology and containers into their 5GC offerings



5GC deal activity ramps up, with incumbents securing migration deals from existing customers

- Vendors are building toward a container- and microservices-based, cloud-native architecture for their 5G core (5GC) products. Following the finalization of the 3GPP's Release 16 specifications in July, initial CSPs in countries including the U.S., China, South Korea and Japan began deploying 5G cores in 2H20. The transition to 5G SA will further accelerate in 2021 as more CSPs seek to take advantage of capabilities including network slicing, ultra-low latency and massive-IoT support. Transitioning to a cloud-native 5G core will yield benefits for CSPs, including opex savings and the ability to provide customers with dedicated network slices. The COVID-19 pandemic has led many CSPs to pull forward investment in 5GC to take full advantage of the benefits 5G SA networks will offer in efficiency and introducing new services. To date, incumbents are the primary beneficiaries of investment in 5GC despite a slow embrace of cloud-native and container technologies.
- Ericsson is bridging EPC with elements of 5GC to support NSA (Non-stand-alone Access) networks as part of initial 5G deployments. Ericsson continues to garner 5GC contracts, which management believes will contribute meaningful revenue in 2021. Ericsson is focused on upselling select 5GC functions to upgrade its customers' Ericsson EPC systems as part of their 5G NSA networks. Ericsson is often winning these upgrades alongside deals for ERS. 5GC deals reached in 2Q20 included China Mobile, China Telecom and Telefonica Deutschland. TBR views Ericsson as ahead of Cisco and Nokia in containerization but lagging in cloud native.
- Cisco's current 5GC product, Ultra Packet Core, is largely a traditional architecture and not cloud native, and Cisco is not perceived as having a strong focus on the 5GC space. Cisco has a massive install base and strong brand power to win 5GC share, but lags competitors in 5GC technology readiness and has a perceived lack of focus on mobile packet core in general. Cisco is leveraging its expertise in network security to differentiate its 5GC solution and enhance its value proposition, and the company recorded a strong reference customer when T-Mobile switched on its 5G SA networks in August. The network leverages technology from Cisco and Nokia, which both supplied T-Mobile's EPC as well.
- Nokia has aggressively partnered with webscales, offering some software through their public clouds. Nokia is likely to add all its cloud-native software offerings, including 5GC, into AWS and Azure. AirGile Cloud-Native Core is Nokia's 5GC offering, and the company has won a share of China Unicom's forthcoming 5GC deployment, as well as Dish's greenfield 5GC deployment.

The largest RAN players will be challenged in the coming years by smaller competitors such as Samsung and disruptors like Mavenir, pushing vRAN

Key vRAN Vendors

AceAxis
Airspan
Altiostar
Amarisoft
Amartus
ASOCS
Baicells
Capgemini (acquired Altran)
Casa Systems
Comcores
Ericsson
Fujitsu
Huawei
JMA Wireless
Lime Microsystems
Mavenir
NEC
Nokia
Parallel Wireless
Phluido
Radisys (owned by Reliance Jio)
Samsung
ZTE

Note: List is not comprehensive.

- vRAN will enable operators to more cost-effectively add network capacity to support escalating data traffic in the 5G era. TBR's research suggests vRAN implementations are around 20% to 30% lower in TCO (capex and opex combined) compared to traditional RAN architectures. These savings are realized via the use of commercial off-the-shelf (COTS) hardware, virtualization and open-source software versus a proprietary, closed system that is currently sold today.
- Disaggregating proprietary RAN software from hardware poses a significant risk to incumbent RAN vendors, namely Huawei, Ericsson, Nokia and ZTE. These incumbents are susceptible to disruption by relatively new companies, such as Altiostar, Mavenir and Parallel Wireless. Samsung, NEC and Fujitsu are also willing to disrupt themselves as they have minimal market share to lose and a lot to gain from pursuing this strategy.
- Mavenir's greenfield play to provide cloud-native solutions is unique and a key differentiator from incumbent OEMs that continue to push their relatively expensive, inflexible and closed systems. CSPs are intrigued by Mavenir's vRAN, not only with the low price points and TCO but also with the performance of its systems in trials and some select commercial production environments. RAN is the domain that will be the catalyst to transform Mavenir into a multibillion-dollar entity. TBR believes Mavenir will take share from incumbent vendors during the 5G network build cycle and that Mavenir is legitimizing itself after winning a bid to provide RAN software for Dish Network's greenfield 5G network build and acquiring ip.access, which gives the company the ability to offer CSPs legacy RAN solutions.
- Tower operators are well positioned to benefit from vRAN implementations, whereby the baseband unit (BBU) is virtualized and housed in a server — an edge site — near the radio site, which could be a traditional tower site or a rooftop site. vRAN will compel CSPs to build edge sites at the base of cell towers or at aggregation hubs in the access layer of the network. vRAN requires edge compute resources to be within 10 miles of the remote radio unit to get the latency to 200 microseconds, which is the maximum threshold allowed to support vRAN traffic.

5GC projects will ramp up in 2021; Microsoft will look to take market share from incumbents by leveraging Affirmed and Metaswitch

Key vCore Vendors

Amdocs (acquired Openet)
Athonet
Casa Systems
Cisco
ENEA
Ericsson
Expeto
HPE
Huawei
Mavenir
Microsoft (acquired Affirmed Networks and Metaswitch)
NEC
Nokia
Oracle
Quortus
Samsung
Sandvine
Twilio (acquired Core Network Dynamics)
ZTE

Note: List is not comprehensive.

- 5GC projects will meaningfully contribute to vendor revenue in 2021 following the awarding of several contracts through 3Q20 and accelerated timelines CSPs have adopted as the pandemic has spurred network transformation investment.
- 5GC is being deployed in China. China Telecom is leveraging Ericsson for Cloud Packet Core, Cloud Unified Data Management and Policy products for its 5GC. 5GC will be deployed on Ericsson NFVI and leverage Ericsson Dynamic Orchestration. Similarly, China Mobile is deploying Ericsson 5GC in five provinces. China Unicom selected Nokia to build 10% of its 5GC network. Nokia is providing its Unified Data Management, Session Management, User Plane, Data Refinery and NetAct products deployed on CloudBand. The remainder of China-based CSPs' 5GCs are likely being provided by Huawei and ZTE.
- Ericsson is benefiting from government bans on using Huawei in mobile networks. In June Telefonica Deutschland selected Ericsson's 5GC after using Huawei for its EPC, while in April BT selected Ericsson's 5GC to replace its Huawei mobile core.
- The mobile core market will face heightened competition from webscale players, especially Microsoft. Microsoft's acquisitions of Affirmed Networks and Metaswitch accelerated the company's foray into 5G, particularly in driving telco network migration into the cloud and advancing its business endeavors by combining its Azure Stack's edge computing offerings with Affirmed's 5GC. Affirmed's 100-plus virtual EPC customers, which include marquee customers such as AT&T and Telus, provide a base to upsell 5GC. Affirmed provides a cloud-based, virtualized environment for running 5G workloads, whereas Metaswitch brings virtualized voice, data and communications solutions for telcos to Microsoft. The acquisitions position Microsoft to win and expand contracts with telcos as they modernize.
- Smaller vendors will also provide competition. Mavenir's 5GC solution was built cloud-native, is backward compatible with EPC, and supports the NSA variant of 5G. However, traction has been limited.
- Dish Network is leveraging Nokia for the bulk of its 5GC, with the vendor providing its cloud-native, containerized SA software that will work well with VMware's Telco Cloud platform, which Dish Network is using to run network functions.

With Nokia's divestment of its Gainspeed portfolio, another diversified OEM reduces its presence in the fixed access domain

Key vFixed Access Vendors

Adtran
Calix
Casa Systems
China Information and Communication Technologies (CICT)
Cisco
CommScope
Fujitsu
Harmonic
Huawei
NEC
Nokia
Vecima Networks
Zhone
ZTE

Note: List is not comprehensive.

- vFixed Access technologies are in the early stages of commercialization. Tests and trials have taken place, but commercial deployments have been limited, though the market is poised to ramp up in the early 2020s. Cablecos' converged CCAPs and telcos' OLTs are fixed access subdomains that will ultimately be virtualized (virtual CCAP [vCCAP] and vOLT, respectively) into a virtualized distributed access architecture (vDAA). Industry initiatives, such as the ONF's VOLTHA project, aim to facilitate and accelerate adoption of virtual fixed access technologies.
- Leading cablecos have been focused on completing DOCSIS 3.1 rollouts, which consumed significant resources. Cablecos' next major investment area will be network virtualization to reap cost efficiencies and other benefits. Comcast has been a leader in this area, spending on uCPE, vCCAP and vDAA, which implicates the operator's aggregation hub sites and requires the use of data center infrastructure in those sites. Other cablecos, such as Charter, Cox, Altice and Liberty Global, are expected to follow in Comcast's footsteps.
- In August Nokia closed the sale of its Gainspeed portfolio, which included DOCSIS DAA and EPON/DPoE technology, to Canada-based Vecima Networks. Nokia acquired Gainspeed in 2016 following the acquisition of Alcatel-Lucent as the company looked to push deeper into the cable access space. However, this strategy did not get traction, and the Fixed Access unit has underperformed. Nokia had been competing with companies such as Harmonic, Casa Systems and CommScope in the virtualized cable access market, including the vCCAP and vDAA spaces. Harmonic has positioned itself as a disruptor in these spaces, aiming to poach legacy market share from incumbent cable access vendors, including companies such as Casa Systems and CommScope. Harmonic enters the space via its heritage as a video infrastructure supplier to the cable industry. In October Casa Systems introduced new infrastructure to enable cablecos to support 5G via their existing networks. The vendor's vCCAP and DOCSIS platforms have been optimized to support 5G traffic for anyhaul and the cable core network.
- Cisco and Huawei have also divested or shut down parts of their cable portfolios to focus on more lucrative opportunities. Both are reducing exposure to cablecos due to depressed spend and, in Huawei's case, trade restrictions. Huawei's wireline focus is shifting to fiber, while Cisco is reducing its focus on cable hardware. This market is increasingly not worth investing in for large, diversified OEMs and will gradually be ceded to niche players.

vIMS is ripe for disruption as more cloud-native solutions are brought to market and provisioned from public clouds

Key vIMS Vendors

Athonet
Cirpack
Cisco
CommVerge Solutions
Dialogic
Ericsson
Huawei
Interop Technologies
Italtel
Mavenir
Microsoft (acquired Metaswitch)
NEC
Nokia
Oracle
Radisys (owned by Reliance Jio)
Ribbon Communications
Samsung
WIT Software
ZTE

Note: List is not comprehensive.

- IMS was one of the first network domains to be virtualized due to the significant benefits derived from virtualizing this technology and the relatively easy migration path to go from traditional IMS systems to virtualized IMS systems.
- Incumbent OEMs were at the cutting edge of aligning with the evolution of this market, and all are major players in the vIMS space. Incumbents will increasingly be disrupted as more nimble and/or cloud-first companies transition their deployment models to offer SaaS-based, cloud-native IMS via public clouds such as AWS or Azure. Ribbon Communications is an example of a vendor striving for this end state. Currently, pieces of Ribbon's IMS portfolio are available with a Bring Your Own License model, with traditional licensing for the software with Ribbon and infrastructure compute resources consumed from AWS and Azure.
- Microsoft will be a more disruptive force in the market following its acquisition of Metaswitch. Metaswitch offers a cloud-native IMS solution called Clearwater Core IMS.
- There is a vibrant ecosystem of more pure play IMS-related companies that support the diverse IMS market, which includes technologies such as Voice over LTE (VoLTE), Voice over Wi-Fi, Rich Communication Services, Unified Communications as a Service, Session Border Controllers and, as 5G proliferates, Voice over New Radio. VoLTE remains a key driver of vIMS spend as more operators globally shift to an optimized, all-IP-based architecture for voice.
- Some companies have a relatively confined market presence limited to a particular region or country (e.g., Italtel [Europe], Cirpack [EMEA], WIT Software [Europe], and CommVerge Solutions [APAC]), while the global network solutions providers have deployed vIMS for customers broadly.

Established technology players stake a claim to routing and switching SDN domain via acquisitions as CSPs increasingly adopt disaggregated solutions

Key Routing & Switching SDN Vendors

6WIND
Arista Networks (acquired Big Switch Networks)
CALIENT Technologies
Cisco
CommScope
DriveNets
Extreme Networks
HPE
Huawei
IP Infusion
Juniper Networks
Microsoft (acquired Metaswitch)
NEC
Nokia
NVIDIA (acquired Mellanox)
Pica8
Pluribus Networks
Pureport
RAD
Ubiquiti Networks
UfiSpace
Volta Networks
ZTE

Key Optical Transport SDN Vendors

ADVA Optical Networking
Calix
Casa Systems
CICT
Ciena
Cisco
Corning
Fujitsu
Huawei
Infinera
Juniper Networks
Nokia
NVIDIA (acquired Cumulus Networks)
Ribbon Communications (acquired ECI Telecom)
ZTE

Note: List is not comprehensive.

Cisco and VMware fortify SD-WAN leadership with acquisitions

Key SD-WAN Vendors

Adaptiv Networks
ADTRAN
Aryaka
Bigleaf Networks
Cisco
Citrix
FatPipe
Fortinet
Fujitsu
HPE (owns Aruba and Silver Peak)
Huawei
Infovista
Juniper Networks
NTT (Virtela)
Nuage (owned by Nokia)
Oracle
Palo Alto Networks
Ribbon Communications
Riverbed
Versa Networks
VMware
ZTE

Note: List is not comprehensive.

- Vendors aim to capitalize on operator demand for SD-WAN. Operators are keen to offer this capability to enterprise customers despite it being disruptive to their MPLS revenue streams. CSPs are striking deals to provide access to SD-WAN platforms and other virtualized network solutions from multiple providers to offer greater choice and attract customers preferring specific vendor ecosystems. AT&T began providing access to Cisco Secure SD-WAN in July to complement the operator's existing VMware VeloCloud SD-WAN offering. In June Verizon added Cisco's 5000 Series Enterprise Network Compute System as a new white-box option to its Virtual Network Services portfolio to attract customers with a preference for a turnkey Cisco ecosystem. Initial VNFs being deployed on the platform include Cisco's SD-WAN service integrated with Palo Alto security capabilities. NTT Communications is using Cisco's Meraki and Viptela SD-WAN solutions to deliver managed services to customers in Japan.
- The SD-WAN market is crowded, with many vendors vying for a piece of the market. TBR expects marginal players will either be acquired by larger players or exit the space. Ultimately, TBR believes the SD-WAN market will consolidate around a few players that will control an outsized portion of market share. Some of the key players TBR believes will remain after the shakeout are Cisco, VMware, HPE and Versa Networks.
- Cisco and VMware are the two leading SD-WAN vendors by revenue. TBR believes Cisco has an advantage in SD-WAN as security becomes a greater consideration in adoption. Cisco is well known for its cloud and end-to-end network security capabilities and is actively baking in security features to Viptela. Technology from the recently completed ThousandEyes acquisition will be integrated with Cisco's SD-WAN, providing deeper network visibility and analytics. In June new integrations between Cisco SD-WAN and its Umbrella security portfolio simplify and automate IT management processes across networking and security. VMware has made significant strides in security via its acquisitions of Carbon Black and Pivotal. Additionally, in January VMware announced its acquisition of cognitive networking startup Nyansa. The deal will embed Nyansa's AIOps platform, Voyance, with VMware's SD-WAN by VeloCloud solution.
- In September HPE finalized the acquisition of Silver Peak for $925 million, which has over 2,000 production SD-WAN deployments across 100 countries. Silver Peak's SD-WAN technology will be integrated with Aruba Edge Services Platform. HPE aims to better-capitalize on demand for remote office and branch office deployments.

Niche MANO players gain acceptance in CSP networks, but large, diversified vendors will secure the majority of business

Key MANO Vendors

Amdocs
Anuta Networks
Arrcus
AsiaInfo
Ciena
Cisco
DriveNets
Ericsson
Gluware
HPE
Huawei
IBM (owns Red Hat)
Innoeye (pending acquisition by Rakuten)
IP Infusion
Juniper Networks
Mavenir
Microsoft (acquired Metaswitch)
Mycom OSI
Netcracker (owned by NEC)
Nokia
RackN
VMware
ZTE

Note: List is not comprehensive.

- There is a growing list of vendors (incumbent and startups) and open-source initiatives (e.g., Akraino) aiming to provide MANO-related software that will enable and support distributed computing. Aspects of the MANO stack will go the open-source route as a more cost-efficient means of standardizing foundational code, while others will stay proprietary.
- IBM's Red Hat and VMware are key players in MANO for distributed computing, and both vendors are already well positioned in this area as it is an extension of their existing capabilities and businesses — IBM from a cloud perspective and VMware from its IT virtualization heritage. IBM is taking more of an open-source-based approach toward its distributed computing platform (OpenShift), while VMware is emphasizing proprietary offerings, though its offerings do have elements of openness to ensure it can flexibly integrate with other platforms.
- Startups such as Arrcus and RackN will play a role in MANO, but current trends suggest CSPs will leverage incumbent players for the foundational aspects of their MANO platforms and enhance their platforms with startup offerings. Arrcus' ArcOS is a Linux-based hardware-agnostic network operating system that can operate white boxes at scale — a key need in the industry.
- Integrating the acquired Comptel portfolio better positions Nokia to simplify adoption of its software stack by offering a preintegrated set of solutions for hybrid and NFV environments. Additionally, Comptel's service fulfillment software is integrated with Nokia's service assurance, MANO solutions and network management platforms to enable closed-loop automation. Nokia is also making progress in increasing the amount of closed-loop automation in its global delivery centers (GDCs), and 100% of the reports generated by each of its three GDCs are now automated. Ericsson has now integrated the CENX portfolio, adding to its existing service assurance capabilities to enhance its NFV orchestration solution, including with CENX's closed-loop automation.

Acquisitions and Alliances

Market incumbents use acquisitions to quickly build out their BSS and cloud-native network monitoring portfolios to support 5G use cases

TBR Assessment of Recent Acquisitions

Strategy

- Acquiring to reduce time to market and partnering to align with NFV's open approach are required strategies for would-be NFV supplier leaders.
- Most acquisitions will continue to involve large incumbents acquiring startups for their point-solution technology and account traction.

Viavi Solutions acquires Expandium

In August Viavi Solutions acquired Expandium, a vendor with microservices-based solutions for network monitoring and assurance, to build out its NITRO Mobile portfolio. Expandium's technologies will enable Viavi to support customers' cloud-based 5G mobile core networks, which are increasingly complex as operators create multivendor environments based on virtual machines and containers. In addition, Expandium will enhance Viavi's analytics capabilities by integrating technologies including ML, stream processing and pattern detection capabilities.

Juniper Networks acquires Netrounds

In September Juniper Networks announced its intent to acquire Netrounds for an undisclosed sum, which is expected to close in 4Q20. Netrounds will complement Juniper's automated WAN offerings with solutions for testing and monitoring SD-WAN environments. This will also improve Juniper's position in the 5G space, as Netrounds' technology can be used to analyze edge networks after cloud-based solutions are configured at the edge. In addition, Netrounds will add new capabilities for testing 5G network slices prior to commercial deployments.

Amdocs acquires Openet

In August Amdocs completed its $180 million acquisition of Openet, an Ireland-based vendor with BSS, 5G charging, data management and policy solutions. While Openet previously competed with Amdocs and the vendors' offerings overlap in areas such as BSS, Openet's cloud-native 5G charging capabilities will complement Amdocs' commerce and billing portfolio. Once integrations between the two vendors' core portfolios is complete — by approximately 2H21 — Amdocs will cross-sell Openet's solutions into its customer base of roughly 350 global CSPs.

Rakuten pushes its ORAN go-to-market efforts on a global scale via Tech Mahindra and Telefonica, while Vodafone tests uCPE platform with Arm

TBR Assessment of Recent Alliances

Strategy

- Operators broaden the availability of their software-mediated network services via wholesale partners and by offering virtualized solutions from multiple vendors.
- Alliances are designed to improve interoperability between complementary products, often at the request of customers.
- Some operators are bundling cloud solutions from webscale providers such as AWS and Microsoft to differentiate their portfolios and to support unique customer needs.

Rakuten names Tech Mahindra as its global go-to-market partner for RCP

- In September Rakuten purchased Tech Mahindra's share of Altiostar, which will enable Rakuten to augment its RCP with Altiostar's open vRAN technologies. Following the sale, Rakuten named Tech Mahindra as its preferred global go-to-market partner for RCP. The alliance will help reduce Rakuten's go-to-market costs — which will inevitably grow amid global expansion — as Tech Mahindra resells RCP and fulfills customers' systems integration needs. TBR expects the vendors' joint efforts will initially focus on Tech Mahindra's home market of India, then will expand into the U.S. where Rakuten is establishing a base of operations in California for sales and marketing efforts across the Americas.

Telefonica teams with multiple open RAN partners

Telefonica is working with multiple partners on its open RAN strategy:

- Telefonica is collaborating with Altiostar, Gigatera Communications, Intel, Supermicro and Xilinx to support its open RAN deployments in Brazil, the U.K., Spain and Germany. The deployments will start with pilots in 2020 to 2021, followed by initial deployments in 2021 to 2022, large-scale deployments across the regions in 2022, and roughly 50% of open RAN deployments will be completed by 2025.
- Rakuten and Telefonica announced in September they are collaborating in areas including the development of open RAN hardware and software, the research of AI use cases within open RAN architecture, and refinement of Rakuten's Innoeye-based OSS platform.

Vodafone collaborates on uCPE platform

- In August Vodafone announced it teamed with Arm, Telco Systems and NXP Semiconductors to test a cloud-native uCPE platform at Vodafone labs in the U.K. The platform supports VNFs such as SD-WAN, firewall and routing solutions and will help to reduce costs while improving energy efficiency and the performance of networking equipment.

Appendix

Definitions

5G	Mobile access technology that can provide wireless, fiber-like performance
AI	Simulation of human intelligence in machines that are programmed to think and act like humans
CDN	A content delivery network (CDN) is a geographically distributed group of servers that work together to provide faster delivery of internet content, typically video.
Cloud	On-demand computer resources that are accessible without direct, active management or ownership of the infrastructure by the user
CORD	Central office rearchitected as a data center (CORD) is a means of modernizing existing central offices into data centers that are capable of supporting CSPs' network virtualization and edge computing requirements. CORD leverages NFV, SDN, open software and commercial off-the-shelf (COTS) hardware to achieve its goals.
Edge Computing	Placing data centers in close proximity to data origination sources
Latency	Time it takes to carry out an action in the network
MANO	Software platforms that manage and orchestrate network resources in a virtualized environment; management and orchestration (MANO) leverages automation and is responsible for policy management. TBR's definition aligns with the European Telecommunications Standards Institute's (ETSI) definition of MANO, which includes NFV Orchestration (NFVO), VNF Manager (VNFM) and virtualized infrastructure manager (VIM).
NFV	Network functions virtualization (NFV) applies IT virtualization technology to the network and consolidates network functions onto industry-standard, high-volume servers, switches and storage, which could be located in central data centers, at the edge, or on the end user's premises. NFV involves the implementation of network functions in software that can run on a range of industry-standard server hardware and that can be moved to, or instantiated in, various locations in the network as required without the need to install new equipment.

Definitions

NFVI	Network functions virtualization infrastructure (NFVI) includes hardware (predominantly data center equipment such as servers, storage and switches) and close-to-the-box software such as operating systems and infrastructure management platforms that compose the physical layer in which VNFs are housed.
Optical Transport	Separating the control plane from the data plane in optical transport infrastructure
Router	A software-based routing framework that allows the host machine to perform as a typical hardware router
SDN	Software-defined networking (SDN) is an approach to networking in which control is decoupled from the physical infrastructure, allowing network administrators to support a network fabric across a multivendor environment.
SD-WAN	Instance of wide area network (WAN) where SDN is leveraged to create an abstracted management layer, enabling it to automate traffic flows through enterprise network fabrics
Switch	A software-based switching framework that allows the host machine to perform as a typical hardware switch
uCPE	Universal customer premises equipment (uCPE) includes COTS x86-based hardware appliances that are used to deliver virtualized network services to the end user's premises. Also includes webscales' on-premises CPE, such as AWS Outposts, Google Anthos, and Microsoft Azure Stack.
vFixed Access	Separating the control plane from the data plane in fixed access infrastructure
vIMS	Virtualizing elements of the IP Multimedia Subsystem (IMS); includes virtual session border controllers and voice over LTE (VoLTE)
vMobile Core	Virtualizing elements of the mobile packet core network for wireless networks
VNF	Virtual network functions (VNF) are individual network functions, such as firewalls and routers, that exist in a software state and are instantiated in a server.
vRAN	Virtual radio access network (vRAN) — virtualizing and decoupling elements of the radio access network, such as the baseband unit (vBBU); includes macros, small cells and distributed antenna systems (DAS)
White Box	ICT hardware, such as x86 servers, that is built with industry standard components

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