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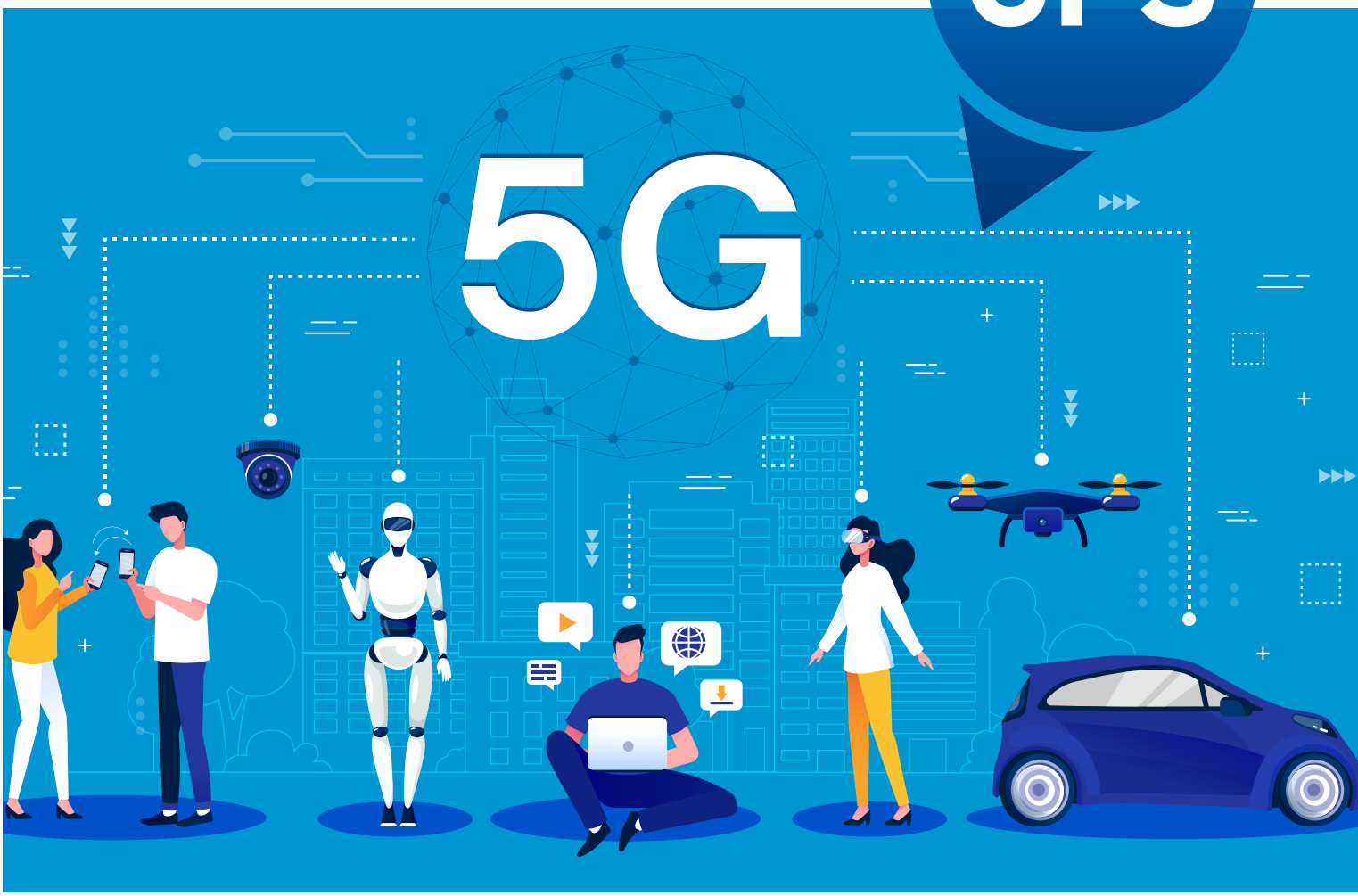

5G AND MOBILE OPERATORS

Is Virtual Becoming Real?

Citi GPS: Global Perspectives & Solutions

April 2020

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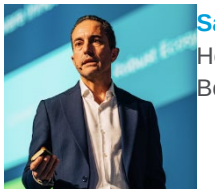

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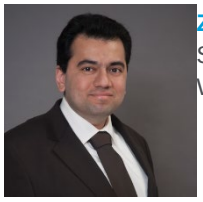

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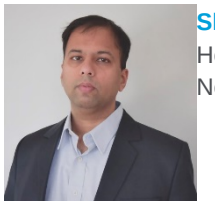

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5G AND MOBILE OPERATORS

Is Virtual Becoming Real?

Kathleen Boyle, CFA
Managing Editor, Citi GPS

Over the past couple of years we have published several Citi GPS reports that look toward the future and highlight wonderful new advances on the horizon — the likes of the Internet-of-Things, driverless cars, virtual reality, smart cities, and factories of the future. A common thread throughout the reports is an assumption that 5G will be the telecom infrastructure backbone that will be needed to enable these products and services.

5G offers improvements in reliability, ultra-low latency that decreases the time lag to transmit data, and device synchronization, which allows data to be transmitted without losing any information. The eventual explosion of more advanced IoT devices could be better supported by 5G networks. Factory robotics, security/delivery drones, and logistics networks, for instance, could be better facilitated with 5G services. Autonomous vehicle connections can be done on 5G, allowing for almost zero latency situational awareness.

In the factory of the future, 5G will allow devices on the factory floor to communicate with each other with security, latency, and reliable machine-to-machine communication. For IoT to work in assisting smart city initiatives there needs to be a sufficient telco network layer to perform the connectivity to the relevant platform and applications. Telecoms are thus the thread which connects all the pieces together. In addition to higher speeds, 5G also allows ultra-low latency (1 millisecond or just 10% of that of LTE) and the ability to host up to a million devices per square kilometer at the same time (10x more devices vs. LTE).

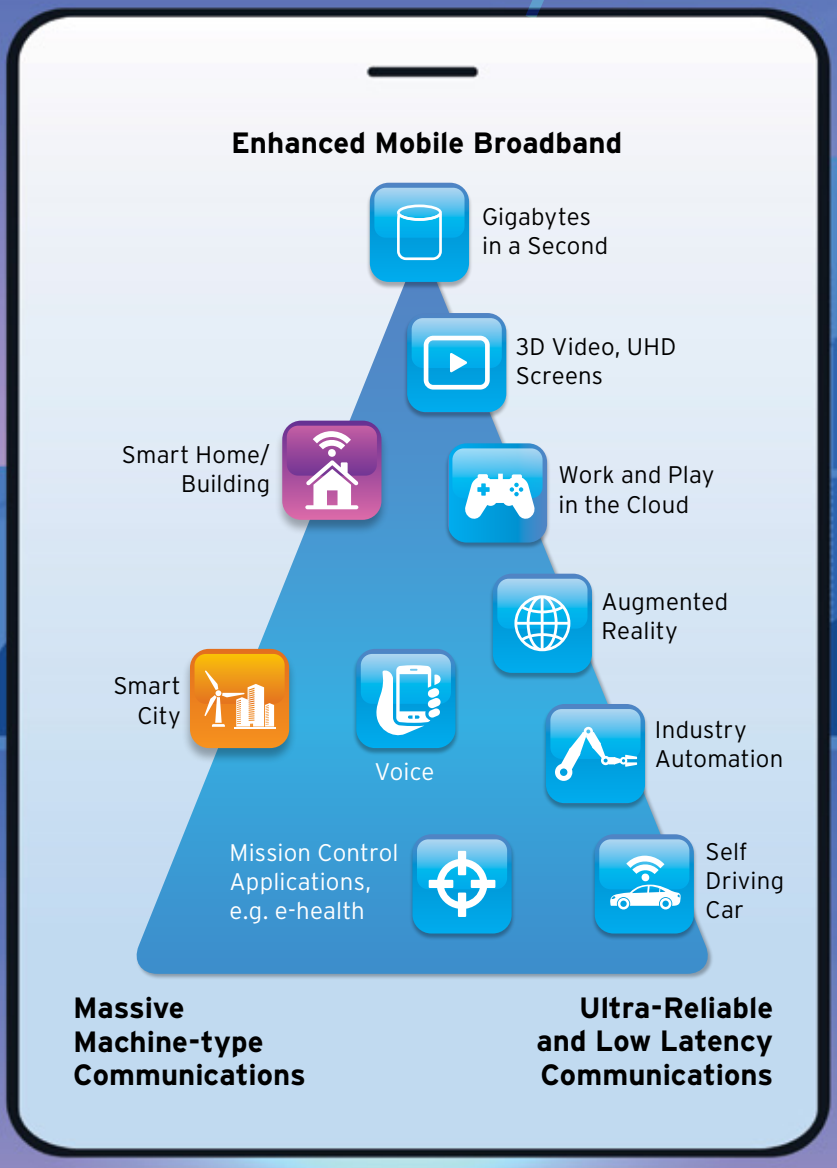
In a 2016 Citi GPS report *Re-Birth of Telecom into a New Digital Industry* we noted how over the past two decades, telecom companies have been busy building infrastructure that is critical to the communications sector and how these networks are now the backbone of our increasingly digital economy. In the report that follows, we look at the how the ramp-up in investment for the next-generation 5G network is starting but note the scale and the scope of this upcoming transition will be challenging, the opportunities may take time to develop, and the path to monetization is uncertain.

Virtualization — the process of separating software functions from the hardware in a network — is one approach being used by operators to unlock significant benefits in terms of agility, time to market, cost, development of applications, initially in their core networks. In addition, virtualization is the minimum requirement to deal with the complexity of the new 5G network architecture and the services that come with it.

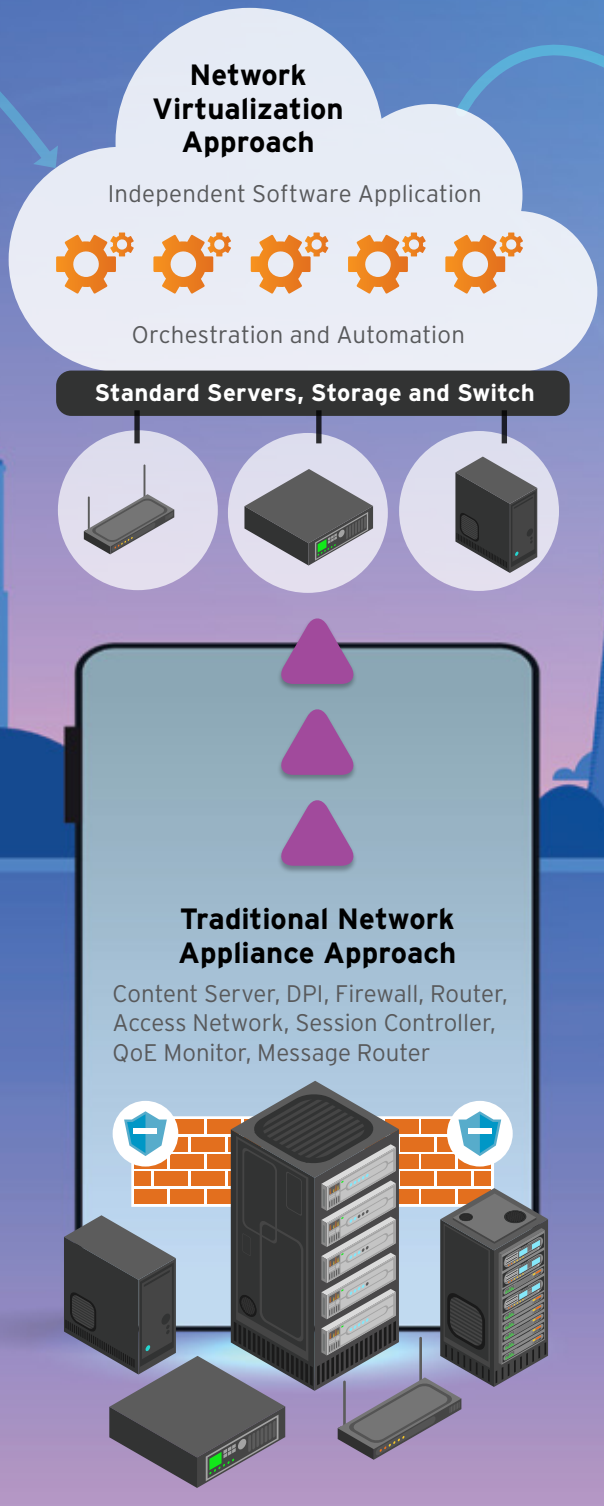
One step further is virtualizing the Access network through Open-RAN, which is an initiative for designing and building radio network solutions using general-purpose, vendor-neutral hardware and software-defined technology. With 5G, this means operators wouldn't have to replace all the technology in their network in order to upgrade them for 5G. Open RAN can help mobile network operators differentiate their services and, if equipment vendors open up the interface between the radio and the broadband unit, can also foster innovation by allowing multiple smaller developers to deploy their software on generic hardware, giving operators flexibility and a more agile network. Allowing mobile network operators more flexibility in the hardware and software of their network through Open Ran should help them to avoid being the 'dumb pipe' for the digital ecosystem and instead embark on a digital transformation.

5G, Densification, and Virtualization

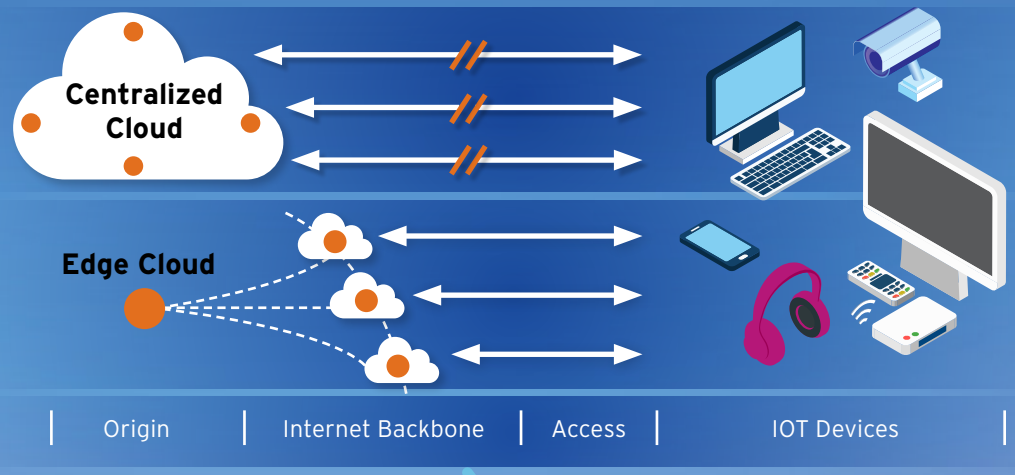
THE STORY AROUND 5G ISN'T JUST ABOUT HIGHER CAPACITY- IT'S A WHOLE RANGE OF NEW/ VARIOUS USE CASES



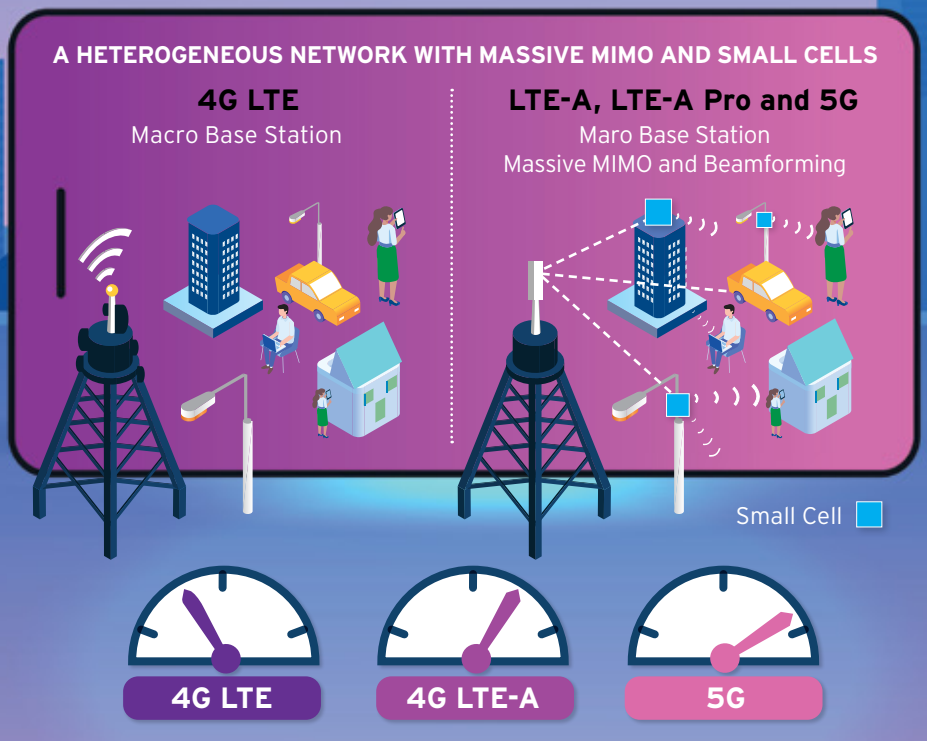
IN ORDER TO UNLEASH 5G, THE CORE NETWORK OF MOBILE OPERATORS NEEDS TO BE MORE AGILE



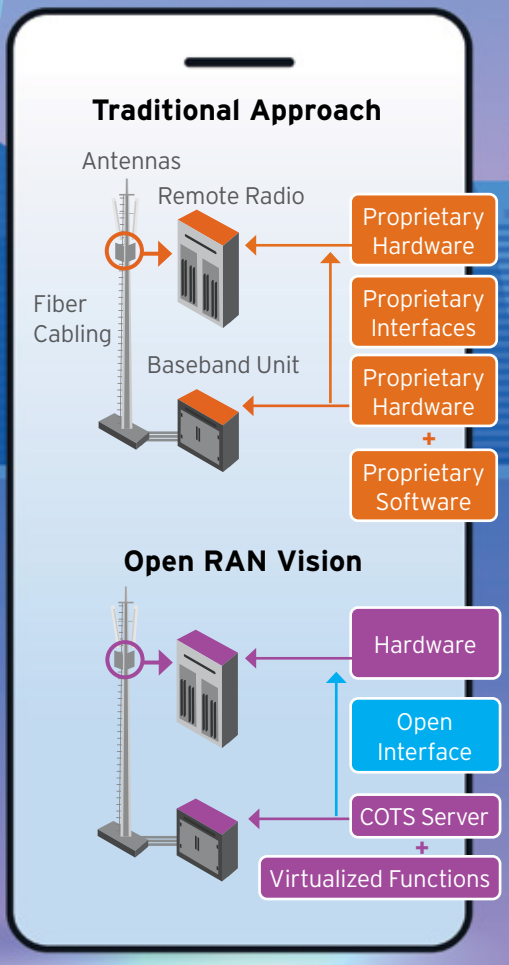
IN ORDER TO DRIVE LOWER LATENCY APPLICATIONS AVAILABLE THROUGH 5G, NETWORKS WILL NEED EDGE CLOUD



THEY'LL ALSO NEED TO INCREASE THE CAPACITY AND DENSITY OF THEIR NETWORK BY MOVING AWAY FROM TODAY'S ARCHITECTURE OF MACRO CELLS TOWARDS SMALL CELLS



EDGE CLOUD AND LOW LATENCY ALSO HELP DRIVE RAN VIRTUALIZATION OPENING THE PATH TO OPEN RAN



Contents

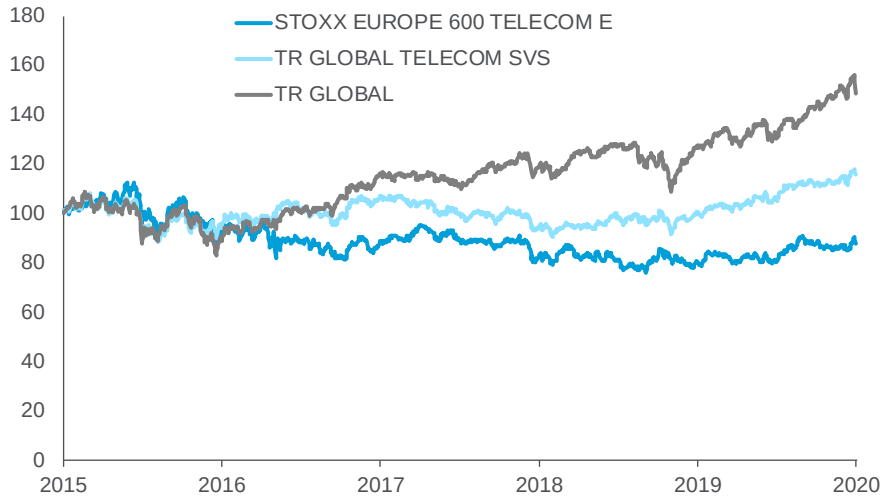
Key Messages

In previous reports, we suggested two options for telecom operators: (1) streamline their business and continue providing the 'dump pipe' to the digital ecosystem; or (2) embark on a digital transformation

In a 2016 Citi GPS report Re-Birth of Telecom into a New Digital Industry we noted how over the past two decades telecom companies have been busy building infrastructure that is critical to the communications sector and how these networks are now the backbone of our increasingly digital economy. Some of the world's largest global companies generate their profits using the network infrastructure built out over the past few years. Over the time period telecom operators have seen only minimal industry growth while Internet Services companies are seeing growth at least six times higher. At the time, we suggested two options for telecom operators: (1) streamline their business and continue providing the 'dumb pipe' to the digital ecosystem; or (2) embark on a digital transformation.

Since we published that report, telecom service revenues have remained under pressure in most parts of the globe. And today, the pressure to invest in new technologies — whether fiber-to-the-home (FTTH) or 5G in mobile — has grown ever greater. The combination of anemic top line growth and rising investment needs has led to continued pressure on telecom operators and they continue to underperform the broader market, particularly in Europe.

Figure 1. European Telecoms Have Been in Decline for Over 3.5 Years



Source: DataStream

5G Could Be More of the Same: Uncertain Returns on High Investment

The biggest development in today's telecom market is the upcoming shift to the fifth generation of wireless technology, or 5G

The biggest development in today's telecom market is the upcoming shift to the fifth generation of wireless technology, or 5G. This transition is likely to unveil huge opportunities for the industry as 5G utilizes higher frequency bands (which enables network densification), and delivers low-latency applications (using edge cloud) and has the potential to generate new services and revenue streams for operators. But the scale and scope of this upcoming transition will be challenging, the opportunities may take time to develop, and the path to monetization is uncertain. In addition, the investment needed to roll out 5G — including spectrum, deployment costs, and changes to architecture — is both significant and front-loaded. A major risk for telecom operators is that 5G will be another round of investment that fails to deliver high returns, a continuation of the issues faced over the past five years.

Vendor Ecosystem Offers Little Choice

A concentrated telecom equipment market severely limits vendor choice and reduces operator negotiating power and their ability to lower costs

The telecom equipment market which supports mobile operating networks and the rollout of 5G is increasingly concentrated around three large vendors which control 80% of the Radio Access Network (RAN) market (with four players accounting for 90%). In 2019 the U.S. imposed an outright ban on Chinese-sourced networking equipment being used to build its 5G network and encouraged other nations to follow, driving the market to higher levels of concentration. Canada, Australia, and New Zealand have also opted for a full ban on Chinese vendors while the U.K. has agreed to a partial ban, limiting Chinese vendor participation to 35% of the RAN while imposing a full ban on the core network. Other European countries are expected to rule shortly[1] on whether they will follow the U.S. lead. The implication of increasing concentration in the telecom equipment market is that vendor choice is severely limited, which could then potentially lessen the negotiating power of operators and limit their ability to reduce costs.

But There Is Change in the Air

Virtualization — the process of separating the software functions (services) from the hardware in a network — can be transformative

Virtualization — the process of separating the software functions (services) from the hardware in a network — could be an important pillar for transformation. With virtualization, software can be run on any generic hardware instead of being embedded in proprietary hardware. In fact multiple software applications can run on a single piece of generic hardware and the software can be instantly upgraded without replacing the hardware. With virtualization, specified hardware gets replaced by software. This is what happened with smart phones (hardware), where multiple appliances such as radios, TVs, cameras, calculators, phones, and even computers were replaced with one smartphone running multiple apps (software). By separating the software from the hardware and getting rid of specialized appliances, the full potential of networks can be unleashed.

Virtualization is the minimum requirement to deal with the complexity of the new 5G network architecture

Most mobile operators are already in the process of virtualizing their core network, to unlock significant benefits in terms of agility, time to market, cost, development of applications, and minimal disruption. In addition, virtualization is the minimum requirement to deal with the complexity of the new 5G network architecture and the services that come with it.

With core networks already going virtual, the next step is to transform the RAN network

The next logical transition is to transform the Radio Access Network (RAN), which provides connectivity between devices (phones/computers) and the core network, into virtualized functions, leveraging on some of the cloud investments needed for 5G. Virtualizing this part of the network is an opportunity that did not exist before because of network architecture limitations.

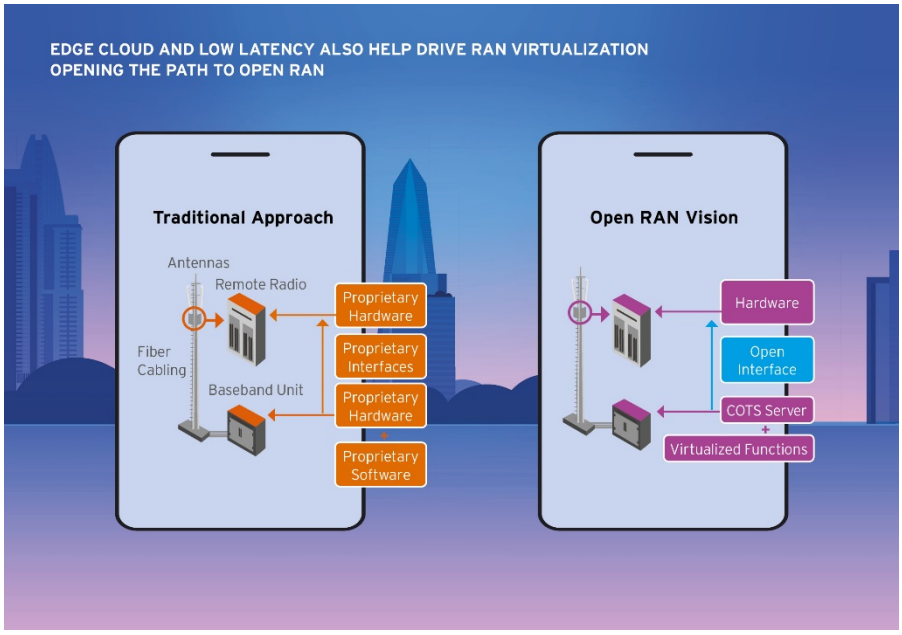
Going beyond virtualization would be moving to Open RAN, which builds RAN solutions using general-purpose, vendor-neutral hardware and software-defined technology

A step further would be Open RAN, an initiative for designing and building radio network solutions using a general-purpose, vendor-neutral hardware and software-defined technology.[2] Today, Open RAN is mainly being deployed, tested, and operated in low density areas and some small urban centers. There, Open RAN is used as a more affordable option in areas where connectivity bottlenecks limit virtualization. But in the urban environment, new vendors supporting Open RAN have virtualization at the center of their solutions. Open RAN needs open interfaces so that multiple vendors can deploy software solutions without the need to keep replacing hardware. An open interface tackles the problem presented by a highly concentrated vendor market and, at the same time, increases innovation and agility.

[1] EU updated on January 29, including the toolbox available for member states https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_127

[2] Telecom Infra Project website.

Figure 2. Increased Flexibility Moving from Traditional Approach to Open RAN Vision



Source: Citi Research

Open RAN as a Key Enabler for Transforming to a DIGITECCS (Digital Technology, Connectivity and Service providers) Model

Open RAN is a path for telecom operators to streamline or transform themselves to deliver returns and regain some of their lost relevance in the value chain

As we highlighted above (and in previous reports), under the current circumstances in the telecommunications industry, telecom operators would need either to streamline or transform themselves to survive and deliver returns. We refer to a digital transformation as a DIGITECCS (DIGItal TEChnology, Connectivity & Service) transformation, which involves: (1) infrastructure sharing, opening, or spin offs; (2) innovative expansion in digital consumer service platforms; and (3) innovative expansion in software-driven/smart network solutions for enterprises. This means moving away from competition and differentiation through the network infrastructure towards differentiating through the digital capabilities of the network and the smart services it offers.

Apart from increasing competition, Open RAN can help mobile network operators (MNOs) with their strategic objectives by enabling the use of multi-vendor software solutions and supplying more choices on how to develop and customize the network.

In a 5G world, applications like the Internet-of-Things (IoT) and network slicing will take a central role. Under an Open RAN architecture, MNOs have more power and control over these applications and the network in general, allowing them to compete through innovation and develop their own services, such as IoT platforms or network slices that they can design and control.

A DIGITECCS model calls for deeper communications infrastructure sharing and better exploration of opportunities in technology and services, both in consumer and enterprise, and we now see Open RAN as a key enabler for such transition. Open RAN is not in itself sufficient to transform the role of operators but it does give them the potential to regain some of their lost relevance in the value chain. It is likely that more investment will need to go into internal IT competencies as operators will need to have the skills internally to be able to engage and develop solutions and form multiple partnerships that can deliver additional services and bring solutions to the market.

However there are Serious Hurdles to Overcome

Challenges for Open RAN include vendor scale and reluctance of equipment vendors to open the interface between the radio and network functionalities to allow software competition

Open RAN will face challenges. The new vendors offering Open RAN solutions lack scale versus traditional vendors and standardization is not yet finalized. At the same time, traditional vendors still control a crucial part of the interface and so far, they are quite reluctant to buy into the idea of opening the interface. Without an open interface to connect the radio (RRU) with the network functionalities (BBU), a complete replacement of the hardware for both components is needed. This is costly. In the U.K., telecom operators were hit by significant costs to replace equipment following the decision of the government to cap the use of Chinese vendors. Put simply, the risk and the cost may be too high for established players to take.

Beware of the Hype but Don't Dismiss its Potential

Global organizations like TIP and the O-RAN Alliance have support from telecom operators to move towards Open RAN

Telecom operators are joining forces — in a way we have not seen before — to support the Open RAN initiative. There are multiple projects around the world working to make Open RAN a reality. The Telecom Infrastructure Project (TIP) and the O-RAN Alliance are two global organizations gathering the main European, Asian, and American operators to work together with vendors to develop specifications and potential solutions and run trials to bring Open RAN to life.

The members of TIP issued the first joint request for information (RFI) for Open RAN solutions in June 2018 with positive responses from seven vendors. The companies launched the first Open RAN trials in Latin America, Turkey, and Africa in 2019 following responses to the RFI.

In the words of Santiago Tenorio, Head of Network Strategy at Vodafone and board member of TIP "*On Open RAN, no one is big enough to make it happen alone. And we all know that. And we have no problem with that. So we have to work together to make it happen. And we're working together to make it happen. And frankly, we're working together really well.*"

Yves Bellego of Orange, a founding member of the O-RAN Alliance, who is actively involved in the development of Open RAN solutions, shares the view that the industry needs to work together to make it happen: "*The way to get vendors to open the interface is by having enough power, that's why it is important to not do this alone. O-RAN Alliance has been created by several operators and we are working on getting more and more operators to support the initiative*".

Commercial deployment of Open RAN has just started

While the solution for Open RAN is not ready yet, especially for 5G technologies, it is developing fast and the trials are expanding rapidly. At the end of 2019, Vodafone announced its intention to extend trials to its entire footprint and has already launched the first trials in Europe (in Ireland and rural areas of the U.K.).

In Japan, Rakuten has embarked on the first full commercial Open RAN deployment and announced it will launch services in April 2020. New entrants in the telecom market may play a crucial role in accelerating the development of technology as they have less to lose (i.e., little or no subscriber base early on, roaming arrangements) and more to gain (no point in replicating the networks of incumbents without the scale). This has the potential to make Open RAN a long-term threat for telecom equipment providers, if it allows for a much lower cost of deployment and a lower cost to run the network. This would be particularly relevant in countries where the equipment cost accounts for a significant part of the cost of deployment versus spectrum, site rental, and other variables. It will also require a lot more in-house expertise as operators need to be able to put together their own solutions, which is where scale will still be an advantage.

Open RAN has gained more popularity lately as global players publicly support the idea and governments (like the U.S.) commit more funding to accelerate development. While Open RAN may take longer to take off than the public currently expects, it may also have more potential than what is anticipated. It remains to be seen whether vendors will open up the interface, operators need to replace existing infrastructure, or new players will emerge as disruptors, but regardless of how it rolls out Open RAN will have huge implications for the entire industry.

> **People tend to overestimate what can be done in one year and to underestimate what can be done in five or ten years.**
>
> – BILL GATES

“”

5G, Network Densification, and Virtualization

A significant revolution in how we view connectivity is coming, including IoT — 5G is a key pillar to this being successful

In many ways, we are on the eve of a significant revolution in how we view connectivity as we transition from the era of connected people to the era of connected devices. The plethora of connections that IoT will enable is just one of many challenges. Over time, it is the diversity of services, their complexity, and their characteristics (increased security, lower latency or lag, and increased customization) that could prove to be the bigger change in enabling new services to take off.

5G is often identified as being the key pillar to enable the transition in connectivity. In the sections that follow, we attempt to look at what changes the roll-out of 5G will drive in network architecture and the challenges facing an industry trying to balance many tradeoffs.

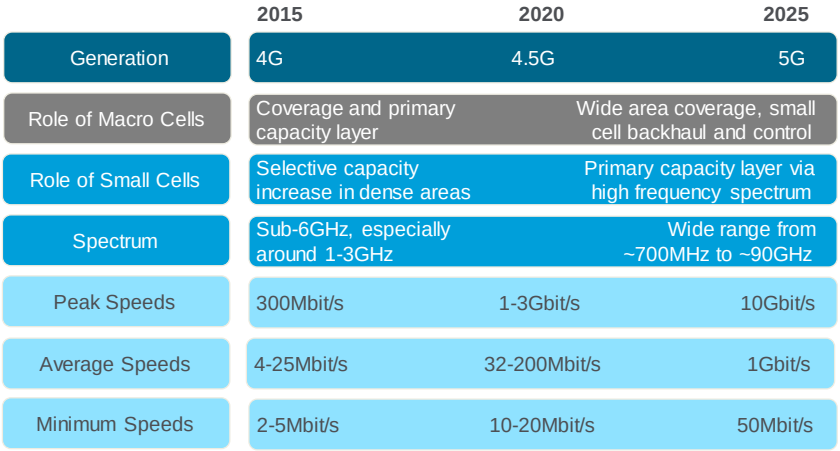
Most mobile network operators are already relatively advanced in implementing or designing virtualization of their core network. Virtualization already enables them to update/introduce services on a regular basis, which reduces time to market and implementation risks. As 5G is a cloud-native technology — meaning its applications and services are built specifically for the cloud — 5G networks are already making substantial progress on dealing with issues at the edge of the network (such as lower latency via fiber and/or improvements in microwave backhauling).This paves the way for virtualization of the RAN (Radio Access Network), which will benefit from the progress made for 5G deployment.

5G May Start as Just Better Connectivity at its Core

5G will drive a dramatic improvement in network performance

It is common to relate to 5G based on headlines talking about new data usage patterns and the current explosion in mobile data. This makes sense as 5G will drive a dramatic improvement in network performance in terms of speed, capacity, and latency as networks densify, higher frequency bands are utilized, and the technology matures. Enhanced mobile broadband is in most cases the main use case of 5G and a natural evolution in terms of experience for mobile subscribers.

Figure 3. Roadmap for the Evolution of Mobile Technologies and Performance



Source: European Commission report "Costing the new potential connectivity needs"

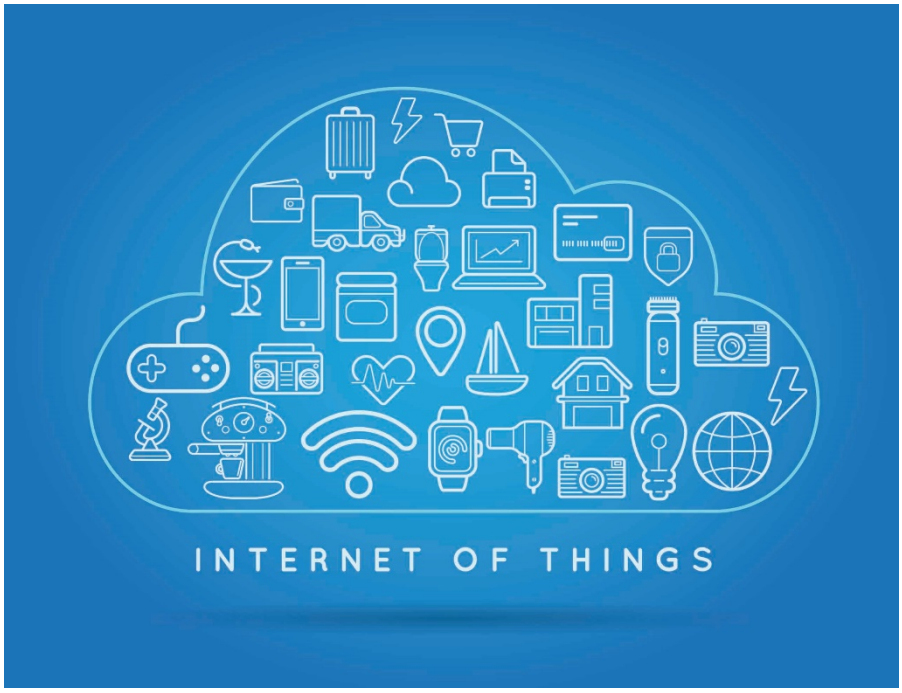
As part of the enhanced mobile broadband (EMB) capabilities being brought about by 5G, fixed wireless services are being launched or planned by various mobile network operators globally. In the U.S., carriers who are leading in the deployment of high frequency 'wireless fiber' are using 28GHz spectrum (vs. 4G wireless spectrum of 600-700MHz). Various players in Europe are looking at fixed broadband substitution, which is already advanced in some countries. Fixed wireless is the best way to deliver home broadband in emerging markets, given the lack of fixed infrastructure in many places

But Services will Extend Beyond

A more important benefit of 5G is the plethora of services and devices it will enable to be connected to the network

Looking beyond today's environment, perhaps a more important driver going forward is the plethora of services and devices that will be connected to the network. IoT can advance only if technology can support multiple devices of different types and with significantly different requirements, while at the same time being able to optimize the services available to enhance the experience where necessary and 'save' where possible (basic narrowband). The requirements for some of the most advanced IoT products of the future require low latency, i.e., a low level of 'delay' before the transfer of data, or very secure applications which inevitably creates more complexity. As IoT evolves, it is possible that multiple applications/platforms will be required to deliver such services. And this is where virtualization is needed in order to be able to have sufficient agility in the network to support these services and to orchestrate their delivery.

Figure 4. The Internet-of-Things



Source: Citi GPS

Diverse Portfolio of Services/Use Cases for 5G

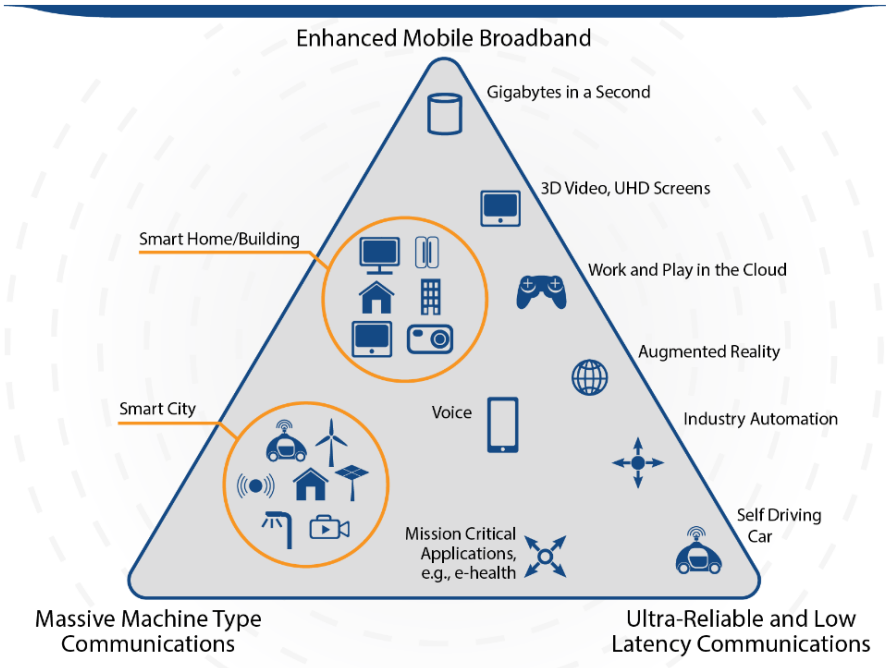
Use cases for 5G include massive machine-type communications, low-latency applications, and network slicing

There are multiple use cases (beyond EMB) that will surface with the roll-out of 5G given its unprecedented speed, latency, and capacity. Some of them aren't known and haven't been developed yet because current networks don't provide the right conditions. However, there are some use cases we already know will be available in a 5G world.

- **Massive Machine-type Communications:** Mobile networks were designed to support and deliver a service based on one device per subscriber and more recently (with 4G) with relatively large data volumes. But they cannot support billions of devices nor their different demands. Networks today are being designed with the capability to recognize the requirements of devices and pass tiny amounts of data efficiently. This 'customization' is important both in smart city applications where a lot of devices are required to share information and when it comes to anything from traffic management to parking to energy consumption (smart meters), noise etc. Individual cloud services for each home would also be possible and this would help tackle security issues and provide more capacity for a single home.

- **Low-Latency Applications:** 5G is expected to deliver very low latency, with almost real time communication between devices. This opens up a world of opportunities like virtual and augmented reality, remote robotic surgery, advanced gaming, immersive entertaining, and eventually drones and self-driving cars (improving time to reaction). For AI-enabled applications to be developed, they need computing to happen at the edge and in real time.

Figure 5. 5G Use Cases Take Advantage of the Technologies' Advanced Capabilities



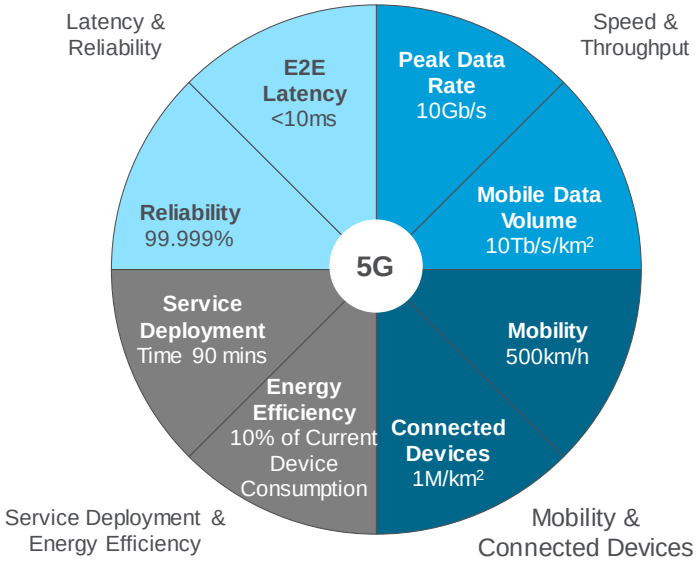
Source: Citi Research

The Main Underlying Feature of 5G is Network Slicing

Network slicing allows the 'production' of multiple virtual networks, which can be set up and 'dismantled' thereby allowing 'network as a service' to be delivered. Various operators are currently operating with network slicing. In Italy, two telecom operators have partnered to pool their spectrum holdings in 5G and co-invest in a common network. One of the partners will receive its own network slice from which it can customize/add its own services before using it to service its base. This arrangement can be used in a similar way to deal with mobile virtual network operators (MVNOs). Network slicing can be also used to offer services to enterprises, industries, events, and IoT markets.

A similar take on the diversity of the new services by U.S. operator Verizon highlights the importance of service deployment and energy efficiency, which are crucial drivers for the development of new services in a cost-effective way. A paper by the GSMA on energy efficiency suggested around a quarter of the overall network savings of 5G are due to its 90% potential reduction in energy use versus 4G.

Figure 6. 5G Ultra Wideband Architecture



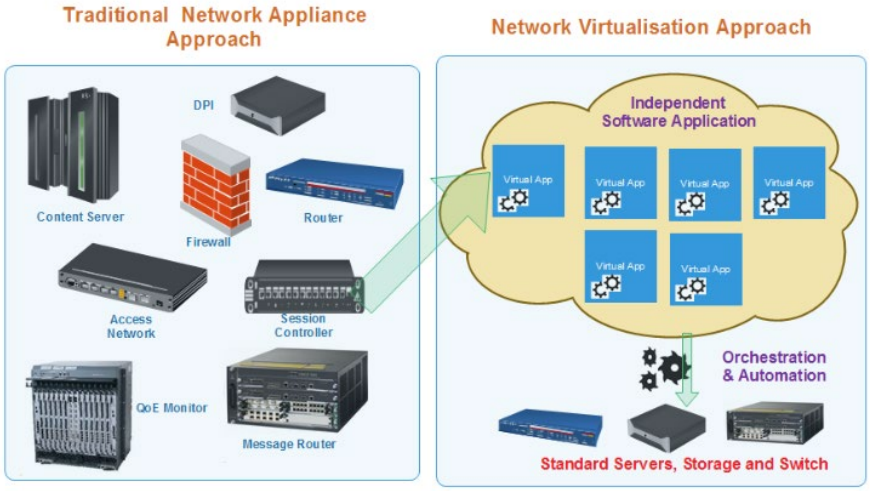
Source: Verizon company reports, Citi Research

Core Virtualization is Just the Starting Point

Virtualizing the core network increases scalability and dynamic management without the same complexity

The starting point for networks to be able to deliver on the 5G potential is for the core to have sufficient agility to deliver on new services in a cost-effective manner. Having specialized appliances (integrated hardware/software devices) to deliver on each of the services/applications needed will consistently add complexity, cost, faults, and delays in introducing services. A software-centric virtual network can be more scalable and deliver without suffering the same complexity. It also allows for more dynamic management of the network using artificial intelligence and machine learning to improve and upgrade the network without the need to deploy engineers or replace equipment.

Figure 7. Transitioning from Traditional Network Appliance Approach to Network Virtualization



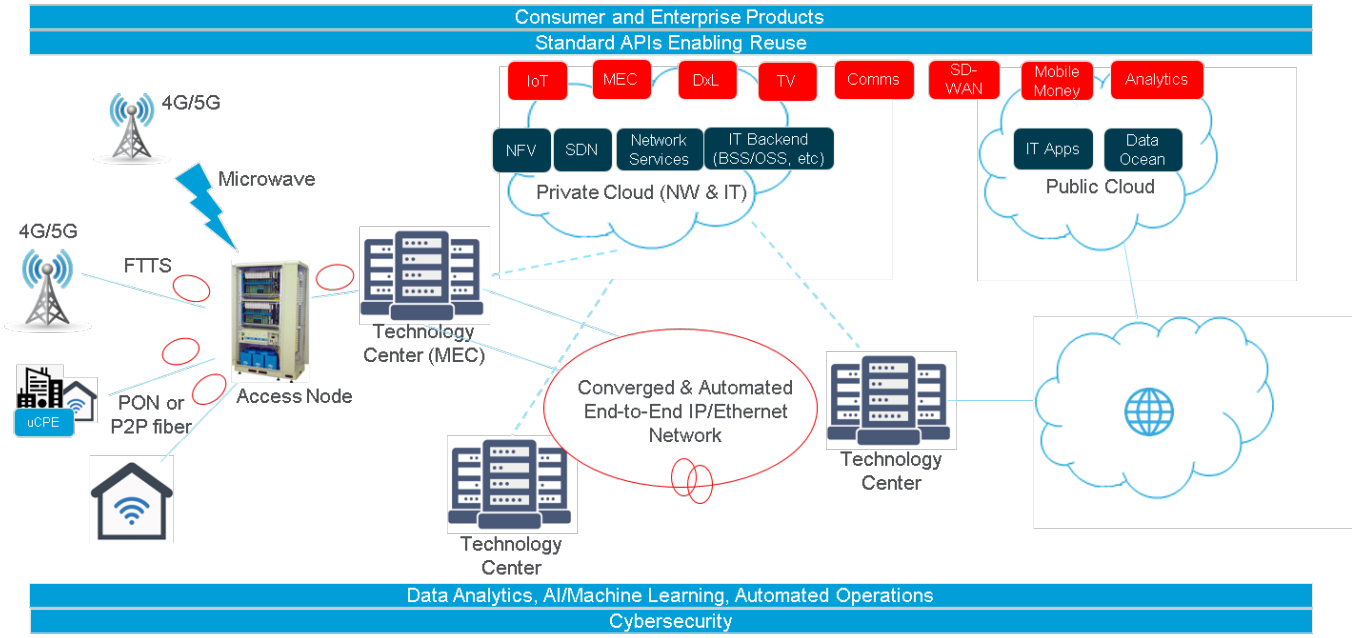
Source: Citi Research

Network agility is probably the most interesting benefit from virtualization

Network agility is probably the most interesting benefit from virtualization: a virtualized core network protects against the failure of a single hardware element. It takes a long time to replace a specialized piece of hardware when a fault arises, but that's not the case with general purpose servers. There are also options to provide extended features for disaster recovery. We talk more about this later in the report in our interview with Santiago Tenorio from Vodafone. Savings are also obvious. The ability to introduce additional features more regularly with lower disruption are obvious advantages.[3]

[3] Core Virtualization allows for platforms that support different functionalities and services to be run over the cloud and at scale vs, the traditional network appliance approach which requires a proprietary hardware device to support each of the services.

Figure 8. Network Architecture Is Evolving in Order to Add Agility via Virtualization: Target Architecture Diagram



Notes: API = application programming interface, BSS = business support system, DxL = digital experience layer, FTTS = fiber-to-the-street, IoT = nternet-of-things, MEC = multi-access edge computing, NFV = network function virtualization, OSS = operating support system, PON = passive optical network, P2P = Point-to-point, SDN = software-defined network, SD-WAN = software-defined networking, uCPE = universal customer premises equipment.
Source: Company Reports

Back to 5G — Densification and Edge Cloud

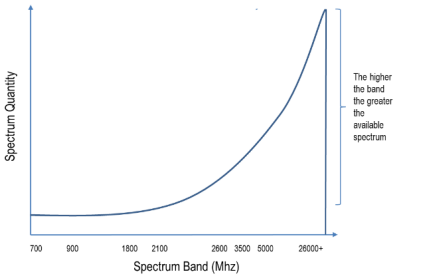
Deployment of 5G will also leverage cell site density and spectrum

Beyond the advantages of more efficient technology, the deployment of 5G will also leverage two additional levers to increase capacity and improve latency: cell site density and spectrum.

Figure 9. The Building Blocks of Network Capacity for a Wireless Network

Source: Citi Research

Figure 10. The Higher the Band, the Greater the Available Spectrum for Telco Use



Source: Citi Research

The two are somewhat related as there is less scarcity of spectrum in the higher frequency bands, but these bands suffer from inferior propagation (and coverage), prompting higher cell density. 5G networks may have similar support when it comes to coverage from low band spectrum (700Mhz in the case of Europe), but mid-band (~2-3.8GHz) and ultra-high band (mmWave spectrum) will be the key drivers of capacity growth and low-latency services.

In order to effectively deploy these spectrum bands, we anticipate operators will need to not just add to the existing megasites but also over time roll out small cells to add capacity to the networks and support propagation. Industry research firm IDC (International Data Corporation) expects over two million 5G small cells by 2021, whereas the existing 2G/3G/4G network, built over many years, has just over 200,000 cell towers according to a PwC study.

Small cells have been deployed to support 4G traffic as well as in preparation for 5G, as evidenced in key markets:

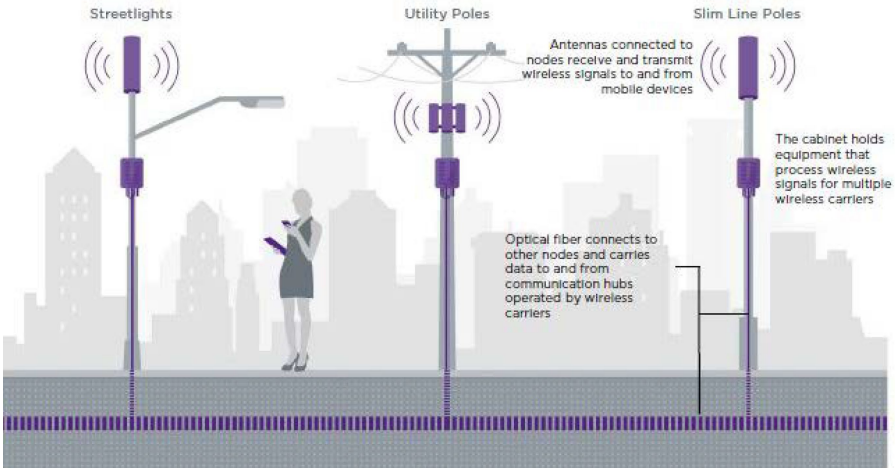
- In the U.S., a study commissioned by CTIA projected more than 800,000 small cells on air by 2026, up from 13,000 in 2017. U.S. operators are already adding small cells to their networks. Deployments are likely to be heavily influenced by spectrum availability. Some are choosing to deploy spectrum and upgrade antennas on macro sites through 2020, whereas others are much more focused on extending fiber (leased and built) and deploying small cells.

- In China, the country's Five Year Plan targets the broad commercial launch of 5G by 2020 while building out small cells. The government is providing support to achieve this target and all operators have signed up to this commitment. A report published by Deloitte in 2018 highlighted that China had been building network sites at unprecedented speeds, far surpassing the U.S. The leading tower site and small cell operator in China has a total of around 1.9 million wireless sites, compared to approximately 200,000 in the United States. The trend has continued over the last couple of years.

- In Korea, telecom carriers began to offer 5G mobile services in April 2019 and have been rolling out 5G services in earnest from 2020. With the commercialization of 5G mobile services, the Korean government announced its 5G-Plus Plan in which Korea will execute proactive public investments to support early-stage growth in key markets while offering tax incentives, investment subsidies, and necessary infrastructure support to attract private investments. They selected 10 core industries, including edge computing, information security, 5GV2X (motor vehicle), (connected) robots, drones, intelligent CCTV, wearable devices, VR/AR devices, next-gen smartphones, and network equipment, as well as five core services, including digital healthcare, smart cities, autonomous vehicles, smart factories, and VR/AR content.

- In Europe, there are no major developments on the small cell front with a couple of exceptions. In Switzerland there is a push to continue to densify the network with small cell deployments, including the use of manhole covers which act as antennas. In Italy, mergers between telecom operators and active network sharing agreements call for a significant densification using the combined mega-cells of two tower companies. Today, each of the two networks uses around 16,000 sites (of which 11,000 are own sites) and the plan for the combination is to be at around 20,000, so not much will really be decommissioned but networks will densify instead. In Germany, about 2,000 sites are being rolled out per year.

Figure 11. Examples of Small Cell Deployments



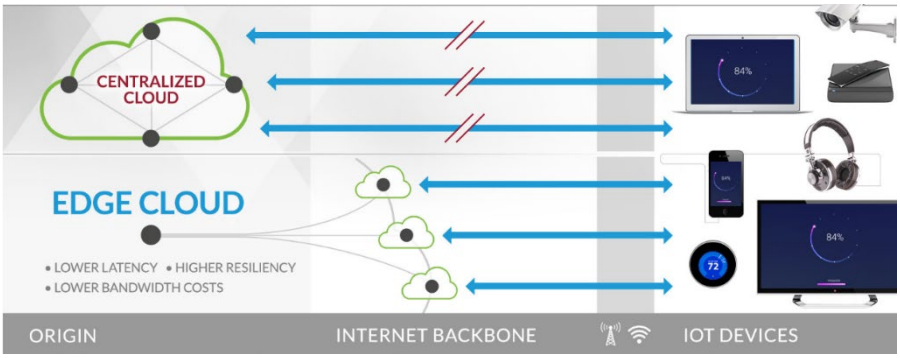
Source: Crown Castle

5G Lives in the Cloud

5G features and services will be supported in the cloud, either being centralized or held closer to the device with edge cloud capabilities

We discussed above how massive volume IoT, low latency, and network slicing applications will require a different approach and different capabilities in the network. All these features/services will be supported in the cloud with non-time critical offerings being centralized while the more time sensitive/low latency applications will be held closer to the device. In order to enable the latter services, mobile network operators will be required to increasingly deploy/access edge cloud capabilities.

Figure 12. IoT and Edge Cloud Workflow



Source: Company website

A lot of the applications that require edge cloud have not yet taken off. And while this may not be the case in the early years of 5G deployments as we highlighted earlier, most MNOs are planning networks to offer these services. Hence, we are seeing partnership agreements already being lined up by operators in order to prepare for the transition.

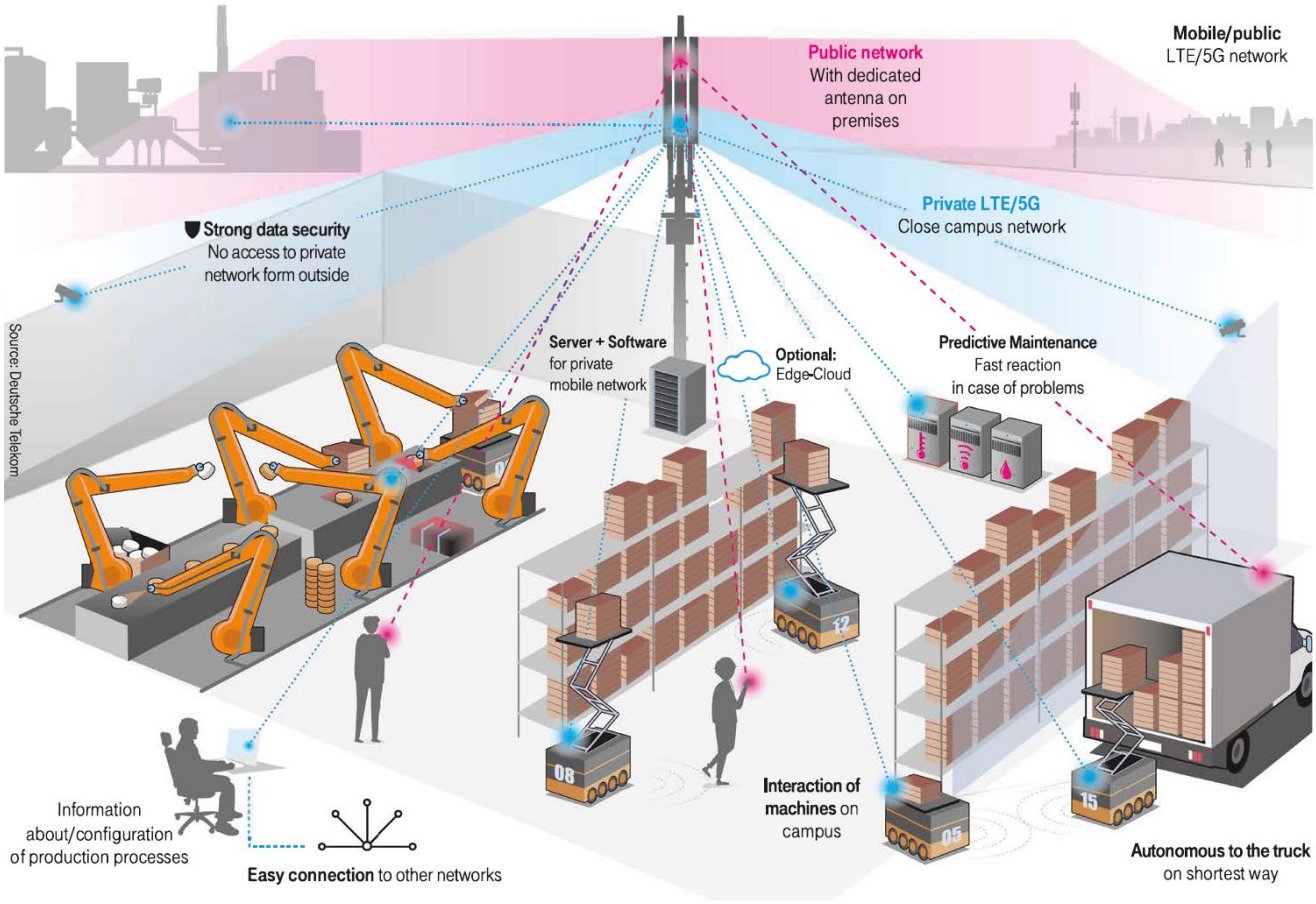
Pushing the Cloud to the Edge: A Visual Overview

Data center demand could increase as a result of 5G owing to colossal data production and real-time data processing

Citi's Asian telecom infrastructure team believes data center providers could stand to be the biggest beneficiaries of 5G. They noted use cases which extend beyond just the synergy of the 5G low-latency services, security, and network virtualization to include private networks/network slices etc.

The intersection of massive IoT devices, artificial intelligence, and 5G speeds will result in colossal data production and real-time data processing. While this will drive demand for data centers, the architecture could evolve as IoT technologies and AI-enabled applications need computing to happen at the edge and in real time. Data centers could become more distributed with more storage hubs in regional markets and smaller cities. Micro data centers could also evolve and be bolted onto existing communications infrastructure, such as telecom towers.

Figure 13. In an Automated Enterprise Set-up, Data Is Processed Locally on the Cloud, thus, Significantly Reducing the Latency Thanks to the Short Transmission Distance



Source: T-Mobile, Citi Research

Macro tower sites have the potential to act as convergence points for wireless access networks, cloud services, IoT, and enterprise networks given the tower's positioning on the edge of mobile networks.

Figure 14. An Instance of Edge Data Center

Source: Citi Research, Vapor IO

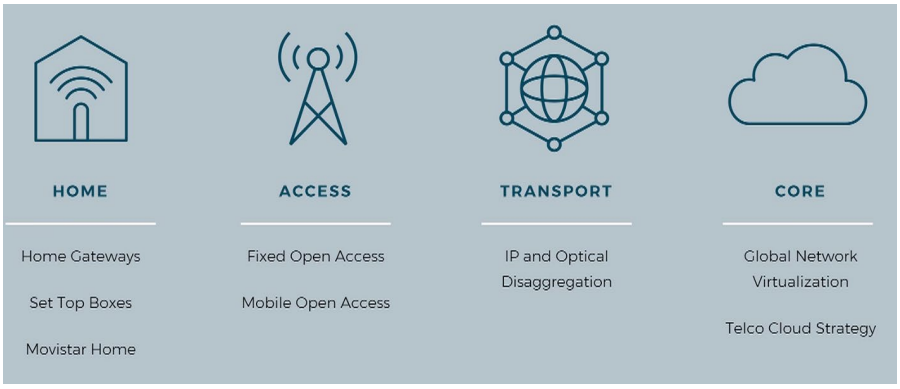
Background to RAN and the Future Architecture

Four key pillars for telecom networks: Home/ Devices, Access, Transport, Core

Telecom networks can be divided into four key pillars:

- **Home/Devices:** This is the termination point, where the network meets the end user in the way of appliances. It usually involves laptops, phones, and SIM cards.
- **Access:** Includes the connectors between the home devices or end user and the service provider. This includes DSL (digital subscriber line), fiber lines, or coax cables providing a broadband connection to the home as well as antennas and cell sites providing mobile signal to the phone.
- **Transport:** The transport network connects access to the core and includes backhauling from cell sites to the exchange as well as the lines from the cabinets to the exchange for fixed broadband.
- **Core:** The core network is where all the equipment that powers connectivity and the intelligence of the service provider resides. This is where all the data and calls arrive, get processed, and are re-directed to another end user or another network provider. The core network is where all the services are defined and is also where providers connect to one another.

Figure 15. Main Components of the Network: How to Drive Openness Across All Parts



Source: Telecom Infra Projects, 2019

The core network and access network, aka RAN, are what we primarily focus on in this report

In this report we focus primarily on the 'access' and 'core' networks. The access network is also known as RAN (Radio Access Network) and comprises, as previously defined, all the connections between telecom operators and users, whereas the core network connects operators to one another and is where all data goes, gets processed, and gets redirected to another network or another user. Both access and core networks contain hardware and software components, which have traditionally been bundled together and managed by the same vendor.

As more services and applications are being used, operators have explored ways to improve the agility and performance of their networks. Similar to other sectors, virtualization is the most effective way to deliver on this front.

Virtualization, in simple terms, is the process of separating or splitting the hardware component from the software component in a network and, in many cases, physical components are replaced by software. The specialized hardware network can be replaced by standard general purpose hardware, while the software components take over all the network functionalities. As software is easier to update and reprogram, it is also easier to add new services and applications.

Virtualization: Parallel Lessons

How apps on a smartphone have replaced individual hardware/appliances is the most familiar example of virtualization

There are a few examples of how virtualization has helped with the development of services. Perhaps the most familiar and clear example highlighting the benefits of virtualization is to look at how today's smartphone has replaced multiple specialized appliances of the past. Services are delivered to the phone via apps and can be updated and upgraded in terms of functionality without requiring hardware changes (well, for a period of time at least).

Twenty years ago, a piece of hardware or an appliance was needed for pretty much every functionality: a radio to listen to music, a phone to make phone calls, a camera to take pictures, a clock for an alarm and to get the time, a video recorder to film videos, a computer to connect to the Internet, and a hard disk to store data. There was nearly one software or functionality per hardware or appliance. Today we can get all these functionalities on any smartphone. This is the impact of virtualization — all services were decoupled from their appliances and became independent software or applications that can run on any smart device.

One piece of hardware can run multiple applications and it is easy to update applications rather than change the hardware/appliance to get the latest version. The concept is similar in the case of network virtualization, with the hardware lasting even longer and easier to scale when using generic hardware.

Figure 16. Virtualization in Pictures

Source: Citi GPS

Core to RAN Virtualization

Most telecom network operators have already moved towards virtualization in their core network

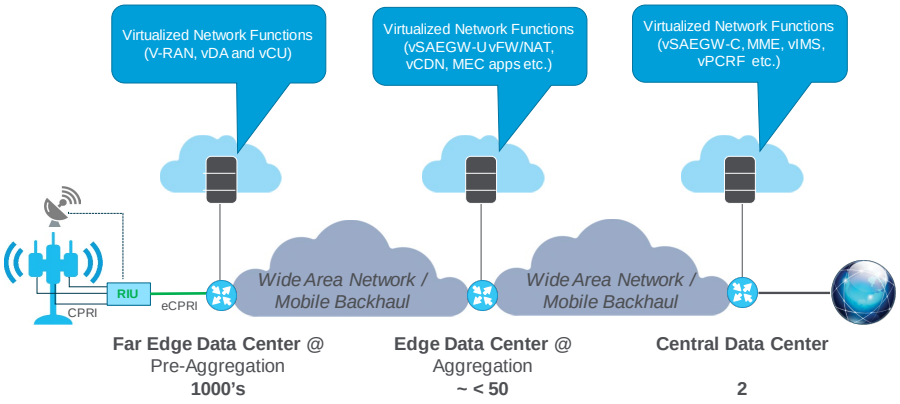
Most operators have already moved towards virtualization but only on the core part of the network, which accounts for a small part of the overall cost of running the network.

Virtualization of the RAN network is just starting

When it comes to the RAN (i.e., the access network), virtualization is something that is just starting. Given the edge cloud capabilities needed for deployment of 5G low latency services, some of the bottlenecks that made virtualization difficult or expensive are now eliminated:

- Edge cloud means the functionality of the cloud can be close to the RAN. This type of functionality needs to be deployed for 5G services anyway, creating a synergy.
- Fiber-like backhauling means the connection with the radio is much more efficient. That is mainly the case in deep urban environments, where some of these 5G application will be initially launched.

Figure 17. Virtualized Network from RAN to Core



Source: Company website, Citi GPS

Virtual Doesn't Necessarily Mean Open

Virtualization can be achieved in different ways

Virtualization should be able to deliver a lot of advantages. But it is important to note that virtualization can be achieved in different ways. Virtual RAN (V-RAN) is envisaged differently both by traditional vendors and new entrants which are more focused on Open RAN.

V-RAN separates the hardware and software in a network, but doesn't open up the interfaces between the radio and baseband

Traditional telco equipment vendors are open to the idea of separating hardware and software but when both still remain controlled by the same vendor. The key to retaining control is the interface that links the RRU (radio) with the BBU (baseband). As long as that interface is closed (controlled by the vendor), then new/different software providers cannot be introduced. Though this is a step ahead of traditional networks and a lot of functionalities and benefits do materialize, mobile network operators are still locked by the vendor and there is little flexibility.

Open RAN advocates are key to open the interfaces of the access networks

Challengers are trying to a degree to replicate the learnings from the core network, where virtualization allowed new software vendors to enter the market. They see virtualization of the RAN as a way to disrupt the market. So challengers champion Open RAN, which goes a step further than V-RAN, though in theory could exist without virtualization. Open RAN advocates are keen to open the interfaces of the access networks. This allows new software vendors to enter the market and deliver their services, opening up the market to more choice and competition. Initially in practice there may be one vendor which is responsible for the functionalities of the network, but over time it should be possible to have multiple independent vendors involved. So for mobile network operators, an advantage of Open RAN is it could give them even more agility and control over their networks.

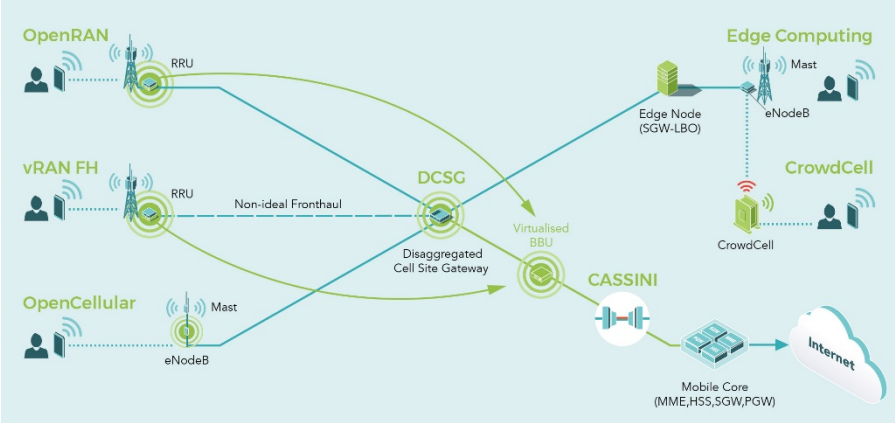
Another difference between traditional vendors and the Open RAN proponents is in how much of the orchestration of the network takes place remotely. This distinction has implications with pros and cons for different services, which we discuss separately in the Appendix of this report.

Figure 18. Traditional vs. Virtualization Models

	Traditional Approach	Virtualization Approach (V-RAN)	Open RAN
Core Network	Contains hardware and software	Hardware = standardized/generic	
Functionalities	Firewall, routers, gateways etc.	Firewall, routers, gateways etc.	
Applications	Proprietary hardware and software for each function	Moving software	
Efficiency	High power consumption, space		
Replacement	Expensive to upgrade or replace	Lower cost	
Access Network	Contains hardware and software		
Remote Radio Unit (RRU)	Proprietary hardware	Proprietary hardware	Generic hardware (COTS)
Baseband Unit (BBU)	Proprietary hardware and software	COTS server+ proprietary softeware (virtualized functions)	
Connection RRU-BBU	Proprietary interfaces (single vendor)	Proprietary interfaces (single vendor)	Open interface (any vendor software)

Source: Citi Research

Figure 19. Interoperability of TIP Technologies



Source: Telecom Infra Project

Main Principles of Open RAN

In a nutshell, Open RAN (O-RAN) is an evolution of V-RAN, which still runs proprietary radio equipment but goes further in terms of virtualization and disaggregation of processors. There is more information as to how each of the three architectures work in Appendix 1.

In Open RAN, the hardware and software are split so it's possible to upgrade the software without changing the hardware, allowing for lower-cost equipment and longer effective life as the upgrade cycle is more aligned with software development

The main principle of Open RAN is to split the hardware from the software across all the points of the network. So with the same hardware components (which themselves can come from multiple vendors), it is possible to upgrade the software, add new features, and even change software vendors.

The advantages of Open RAN on the hardware side are a combination of (1) lower-cost equipment (white box solutions from a variety of suppliers), which can be procured from multiple sources; and (2) longer effective life as the upgrade cycle is more linked to software development rather than a combination of both. It leads to smaller equipment, which may have advantages when it comes to site rental (depending on the structure of the contracts) and cost of deployment. It can also allow for easier RAN sharing, which is agnostic of the choices of the mobile network operators in terms of vendors for other services.

We look at Open RAN in more detail in the next section.

What Does Open RAN Bring to the Table?

The market may be more focused on standards (4G, 5G) and network access (densification via small cells), but perhaps the biggest transformational change in the industry is due to come from a parallel area: end-to-end network virtualization. There are a lot of trade-offs and practical issues that could slow the process but the direction of travel is clear regardless of whether the model used is traditional or Open RAN. In this section, we look at the motivation for mobile network operators to look at alternatives.

Main Benefits of Open RAN: Why Now?

The idea of Open RAN is not new. Yes, virtualization opens up new options and 5G means virtualization of the RAN is closer/easier and maybe necessary to get the full benefit of the services possible over time. But before we discuss some of the technical and other motivations of the past, we believe there is a more pressing issue.

Vendor Market Offers Limited Choice and Innovation

Innovation cycles are lengthening and there is limited choice in equipment vendors on top of falling returns and rising capital needs for operators

In the current environment, network operators are facing falling returns while capital needs are increasing. At the same time vendor options are limited as the industry has consolidated to just three dominant players which hold around 80% of the market. Mobile network operators already believe the cycle of innovation is getting longer. Meanwhile, the savings, which operators grew accustomed to from the shake-up in the vendor industry brought on by the entry of Chinese vendors in 2005 onwards, have ended.

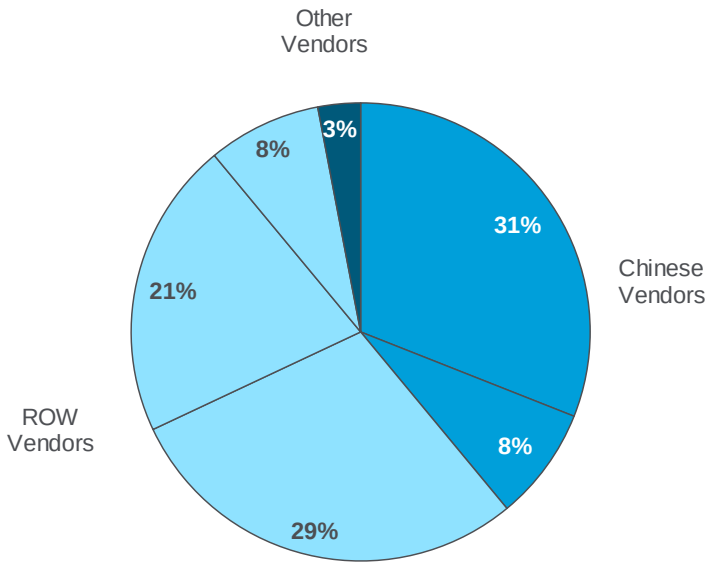
Security concerns over Chinese vendors are further limiting choice in the equipment market

Security concerns over Chinese vendors supplying telecommunication equipment have featured prominently in the press since 2018. The U.S. has been increasingly worried about the involvement of Chinese vendors due to suspicions over the risk of espionage. This started a few years earlier but was aggravated in 2017 following a National Intelligence Law introduced in China requiring corporations to assist in offensive intelligence operations and other cybersecurity measures, which could involve the passing of network data to the Chinese government. The law triggered an increase in measures against Chinese vendors around the world but particularly in the U.S. In 2019, the U.S. president issued an executive order barring U.S. companies from using information and communication technology from anyone considered a national security threat, including the dominant Chinese telecom equipment manufacturer, its subsidiaries, and other Chinese vendors.

Following the U.S. action, Australia and New Zealand imposed an outright ban on Chinese vendors participating in 5G deployment, Japan banned Chinese vendors from official government contracts, and Canada has expressed concerns. Out of the five countries who participate in the Five Eyes intelligence alliance, only the U.K. has opted against an outright ban. Instead, the U.K. plans to improve restrictions but allow ‘non trusted vendors’ to have some role in 5G deployments.

In January 2020, the U.K. announced its decision to ban Chinese vendors from the network core, but would allow non-core technology equipment to be installed until it reaches a maximum of 35% of the overall network.

Figure 20. Mobile RAN Market Share (2019)



Source: Company reports, Dell'Oro, Citi Research

In late January 2020, the EU directed its member states to take steps to ensure 5G security, with new guidelines calling for EU countries to apply restrictions for high-risk suppliers that should be left out of critical and sensitive functions. The decision will ultimately be taken by each member state using the tools the EU has agreed. European countries — unlike the U.K. — are not part of the Five Eyes intelligence alliance. Until a decision is finalized it is difficult to predict the outcome.

In any case, for mobile network operators the choices appear to be limited and if anything are getting more constrained in the traditional vendor model.

Separating hardware and software ensures innovation will continue and new software vendors can enter the market

Moving to Open RAN can open the way for a number of new entrants and increase competition in the market. In addition, by completely separating the hardware from the software in a network, it ensures innovation will continue and the barriers to entry of future software vendors will be even lower. This is especially true if over time the technology matures and also supports in practice the presence of multiple software vendors, potentially each focusing on specific functionalities/solutions in the network.

In short, Open RAN could foster innovation by allowing multiple smaller developers to deploy their software on generic hardware. The ability to have a flexible and agile network will become a competitive advantage.

Other Technical Reasons to Opt for Open RAN

Lower cost of deployment, increased agility and higher security are also benefits of Open RAN

- **Lower Cost of Deployment:** Savings accrue from various factors: (1) smaller equipment, which is more basic and can operate for longer (and thus be amortized for longer); (2) unbundling the software and reducing the value that accrues to vendors; (3) easier shift across vendors/providers; (4) adapting the needs to the environment via more frequent software upgrades/changes; (5) harmonization with one single hardware across the core, RAN, and edge simplifying the management of the network; and (6) a widely adopted open platform could facilitate innovation for new applications. A lot of the efficiencies accrue over time as the technology matures and the 'investment to develop' the new technology is effectively amortized. However, on the hardware side, savings may start accruing earlier.
  - The design of the network when it comes to small cells may also drive significant savings as it can centralize functionalities on the edge, reducing BBU (baseband) hardware investments.
- **Agility:** Some of the factors above also contribute to agility. The bottom line is that operators can engage with more vendors in order to address different features/services and introduce new ones. The cycle for upgrades, updates, and introduction of services can be materially shortened. And over time, as the ecosystem matures, it can allow the operators to have more control over the end product by making their own choices and acting as the aggregators themselves, rather than relying on vendors. Some are applying AI on user data and network data, but more control of the networks will put these to more effective use.
- **Security:** There is increasing pressure relating to security issues coming from politicians, governments, authorities, and others. The topic so far has been closely linked to the security concerns in the U.S. and Europe around the use of Chinese vendors. But security and privacy concerns will remain one of the most sensitive topics for the industry more broadly and extends beyond today's vendor debate. Cloud RAN allows operators to have more control over the network and also more flexibility in choosing/changing vendors across the different components. This minimizes the dependency and ultimately the risk in the event a vendor is put under the spotlight.
  - **Edge as Protection against Cybersecurity Risks:** Another benefit of edge cloud is the ability to fence the network off from cybersecurity risks. Edge computing allows the storage and processing of data on locations near the end user as opposed to centralizing all data in a single location. This helps protect data from security breaches and attacks, while at the same time minimizing the impact if they do occur. When all data is centralized, the risk of data loss or leakage is higher and the exposure is greater than when data is spread over multiple locations. The flipside of this is that all locations would need to meet data security standards to guarantee protection, which can become more costly and harder to monitor.

Strategic Rationale behind Open RAN for MNOs

There are obvious benefits in terms of cost and performance to both V-RAN and Open RAN over traditional networks. To distinguish between the two, we look at the applications that could be facilitated by both networks and where Open RAN could theoretically add value. Before we focus on the implementation risks, we focus on the strategic merits for telecom operators to pursue the transition to Open RAN. Denser networks come at a significant cost and the industry will need to share the burden and then find other ways to add value in different areas. Open RAN could help with the transition and keep the telecom operator business model relevant for longer. It also allows the industry to differentiate on service, rather than access or coverage, and to transition towards the DIGITECCS principles.

Sharing Becomes the Norm

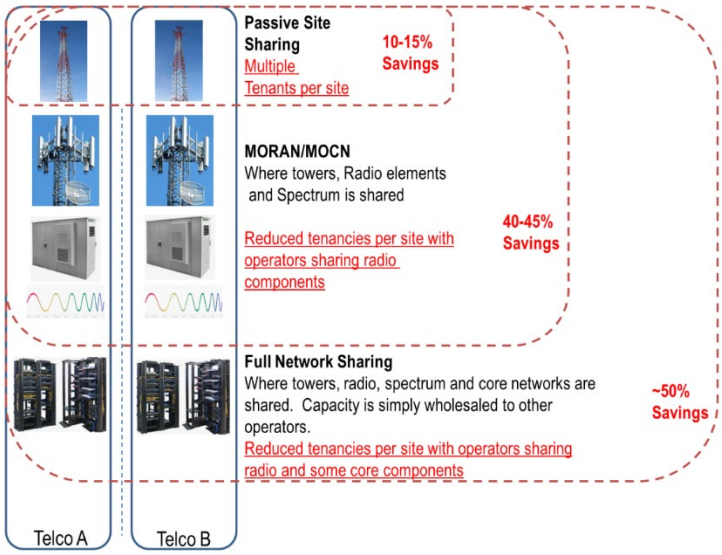
Sharing and splitting the cost of deploying and maintaining the networks is key to help telecom operators densify their networks

Across the globe, telecom operators are being pressured to make significant investments to densify their networks in order to deal with both the raw demand for data and also the architecture needed to deliver new services. Whether it's passive sharing, active sharing agreements, or tacit sharing (via intermediary tower companies), the industry is finding ways to split and share the cost of deploying and maintaining networks.

Tower models thrived as telecom operators moved from no sharing at all to passive network sharing (towers). Given the investments 5G will entail, telecom operators are looking to the next level of network sharing, i.e., active network sharing. This is basically a move towards fully-shared networks (from towers all the way down to spectrum and even core networks), which comes under the guise of wholesaling/roaming.

The deeper the level of sharing, the bigger the potential savings. Deeper network sharing on a multi-operator core network level can save up to nearly 40-45% of network capital expenditure.

Figure 21. Areas of the Network Which Can Be Shared and Cost Savings by Type



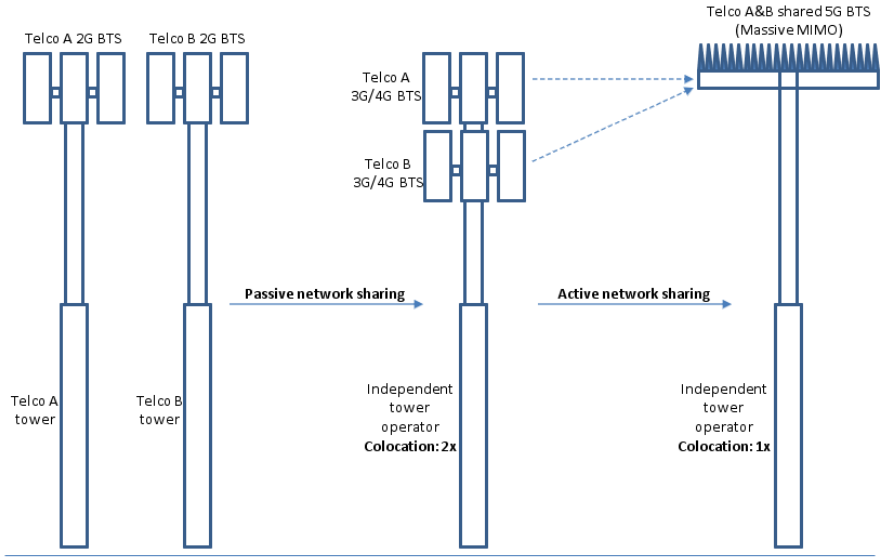
Source: Citi Research

Even with Network Sharing, Net Telecom Infrastructure Demand in the 5G World Is Still Expected to Double

Telecom infrastructure demand is set to increase as the roll-out of 5G picks up steam

Even with network sharing and mergers & acquisitions among telecom operators, we think telecom infrastructure demand is set to increase as the roll-out of 5G picks up steam. This is mainly due to sheer demand on the network elements each carrier has to deploy to meet the 5G specification. Based on our discussions with telecom operators and industry experts, 5G will require ~3-5x the numbers of sites even on the mid-range spectrum in 2.6GHz and 3.5GHz bands.

Figure 22. Passive vs. Active Network Sharing



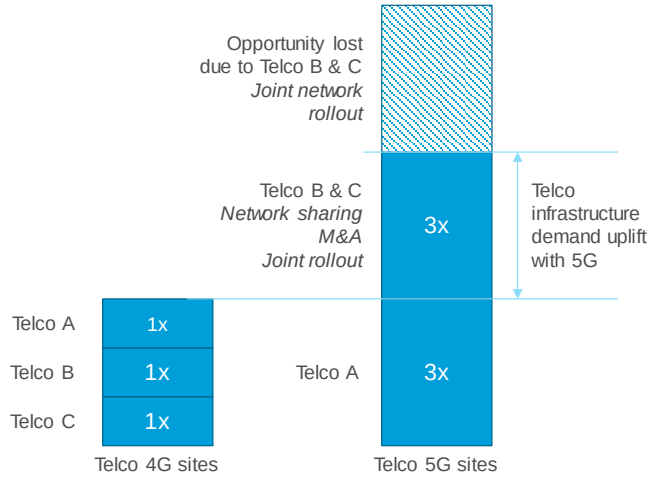
Source: Citi Research

We see a two-fold increase in network densification, led by relatively cheap small cells connected to fiber

Assuming on average that two 5G networks are rolled-out in each market versus an average of three telecom operators due to network sharing or telecom operator M&A, we still see a two-fold increase in network densification demand, assuming three times the number of sites. This has yet to factor in the need for extremely high frequency or mmWaves.

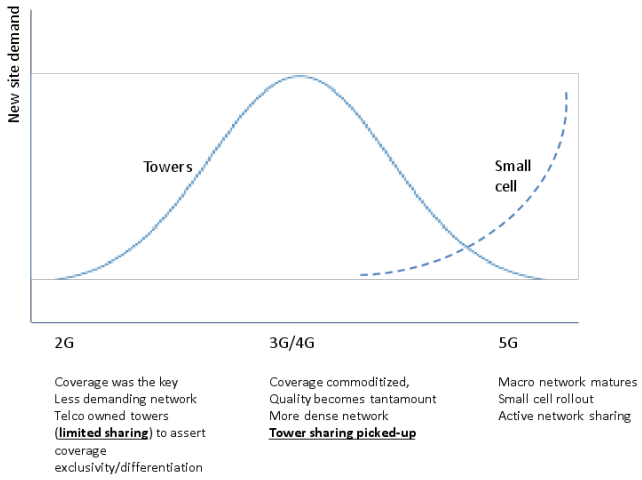
While existing tower operators are set to benefit from the densification needs of telecom operators, we note that a bigger proportion of this densification will be led by relatively cheap small cells connected by fiber. Note the Federal Communication Commission (FCC) observation that 80% of the new cell site demand will be small-cell led.

Figure 23. Net Telco Infrastructure Demand Will Still Be High Even with Network Sharing



Source: Citi Research

Figure 24. 5G Densification Demand to be Led by Small Cells While Demand for New Macro Tower Sites to Subside



Source: Citi Research

Network sharing is likely to become more popular with virtualized networks

Under virtualized networks, network sharing is likely to become more popular. When networks are virtualized, hardware becomes a commodity and each operator can create their own virtual network using the same hardware (site, small cell, antenna). The differentiating factors will become the services and network intelligence that each operator adds to its own virtual network, rather than the current environment which relies on the strategic location of the sites.

Examples of network sharing options:

- **Europe:** There are multiple sharing agreements in place across Europe, including active and passive sharing. Network sharing has been more popular in Europe than in other parts of the world, partly due to lower returns at telecom operators and an underdeveloped tower industry. We have seen agreements in Nordic countries and in the U.K. for many years but more recently, operators in Italy, Spain, Portugal, Germany, and Greece have also reached such cooperation agreements. In Appendix 2 we outline the details of existing sharing agreements on a country-by-country basis

- **U.S.:** Tacit, or passive, sharing is dominant in the U.S. as tower companies own most of the tower infrastructure and operators rent the towers from them. In this way they all use the same physical tower infrastructure (and now small cells) in a 'tacit' sharing model.

- **Asia:** The biggest tower company in the world is in China and it is owned by the country's three largest telecom operators which share their tower and small cells infrastructure through this tower vehicle. Because the towers are already shared, two of the operators announced an agreement to jointly build a 5G network and share the infrastructure. In the two years since its creation in July 2015, the infrastructure sharing facilitated in China has reduced the country's new cell site requirement by 568 000 sites, saving RMB100.3 billion ($15.2 billion) .India also has shared tower infrastructure between its largest mobile operators while the rest of Asia remains less open to network sharing. In Japan, towers are still considered strategic assets and operators are reluctant to engage in sharing.

Open RAN & Network Differentiation: How DIGITECCs Comes In

The key question lies on how operators can differentiate themselves when they share the same infrastructure. With the traditional model, mobile network operators effectively take solutions already developed by established vendors and install them on their networks. There are some tweaks available to them, but the product is mostly developed by the vendor and therefore is also available to other operators in pretty much the same form. Any future solutions, platforms, or services launched under the current model will have some involvement from vendors, which again limits both independence and differentiation.

Open RAN could allow operators to differentiate with customized software, offering different services and features to their customers

But Open RAN could allow operators enough 'flexibility' to differentiate, even if they share most of the physical elements of the infrastructure with their competitors. When software is fully independent from hardware and the RAN is open to allow different providers to insert their own features, operators can then customize the software and differentiate by offering different services and features to their customers.

We have previously introduced the concept of DIGITECCS (DIGItal TECh, Connectivity and Service providers) as a transformative business model for telecom operators given the challenges the industry faces. DIGITECCS means operators put technology/software at the heart of their strategy. It implies that operators pursue competitive differentiation through smart networks and processed big data, while changing their approach to infrastructure by sharing, consolidating, or spinning off assets. Under a DIGITECCS model, telecom operators will sell bundles of connectivity.

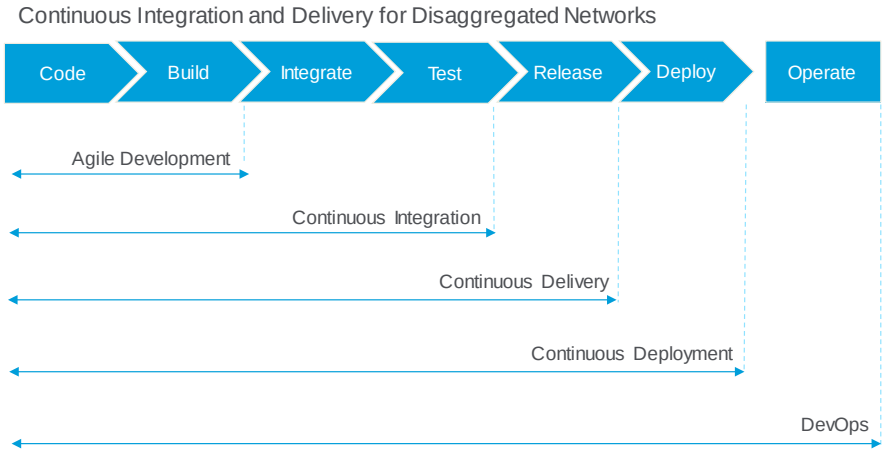
Smart networks will be able to collect big data and adjust their performance based on end-user software.

- **Information Technology (IT) Competencies and Investments:** This is something mobile network operators are already advancing with investment in core virtualization and other services. A decent portion of capital expenditure is already being allocated to IT and that is something operators are expecting to see grow over time, even before any developments on Open RAN.

- **Continuous Development:** Only virtualization can keep driving upgrades on a consistent/regular basis by developing, integrating and testing, deploying, and operating software in a dynamic way. The potential to tap into the competencies and solutions of different vendors also allows for partnerships that can drive differentiation.

- **Leveraging on AI and Other Learnings:** Operators may also be able to utilize network information in order not only to improve the deployment of their networks to optimize performance, but also to add features and solutions by having more direct control over what can be developed rather than waiting for vendors to come up with a product that is more or less available to everyone in a relatively generic form.

Figure 25. Benefits of Separating the Software



Source: Telecom Infra Project 2019

There are two areas of potential differentiation, which operators are particularly focused on capitalizing on over time:

- **Internet of Things (IoT):** Open RAN will allow operators to work with multiple software vendors to deliver unique solutions and applications in parallel. Artificial intelligence, for example, can support the delivery of a full range of solutions to an IoT customer, rather than relying on partnerships and solutions, which traditional equipment vendors offer to everyone.
- **Network Slicing:** Orange believes there is value in having flexibility in designing the network slices saying "*it will give us more flexibility to design the slices and the level of quality of service we deliver in each slice. This will help us differentiate from our competitors.*"

Bottom Line: Scale May Matter Again

With Open RAN, scale and internal IT competencies could start to matter as the sheer amount of choice increases

If Open RAN does take off, we believe it will not be long before scale or at least internal IT competencies (that could come with scale) start to matter. It will be far easier for companies that can develop or acquire competencies to co-develop or put together different solutions from different vendors. The scale of software vendors could also change the dynamic in the market by allowing some exclusive arrangements for new solutions. In short, Open RAN may in many ways increase the complexity of running a network due to the sheer amount of choice available and that could help players with scale to differentiate.

The Long Road to Open RAN

The road to Open RAN has already started but it could be long as there is no smooth transition for established networks to move to Open RAN

In many ways the journey towards Open RAN has effectively started. Whereas a few years ago this was a neat idea for the future, it is now increasingly becoming a reality. A lot of focus naturally falls on Japan, which has so far taken the boldest step in the direction of Open RAN. But in fact, the entire industry is increasingly looking for solutions that will help with the economics and with the flexibility/capabilities of networks over time.

Among established players, two European operators have now announced specific initiatives and a clear timeline for commercial deployments in the next two to three years. We expect others will follow as progress is made on this front and the execution/development risks are better understood. Ultimately, the combination of strong support from the industry and a clear incentive to drive networks in that direction will pave the way in due course.

But the journey could be long as there is no smooth path for established networks to transition to Open RAN, while there are other trade-offs beyond the upfront costs of investment. In this section, we look at the challenges, update the status of some of these initiatives, and give our opinion of where we are heading, caveated given the uncertainties that also lie ahead.

The Risk to Transition: If It's Not Broken, Don't Fix It?

Traditional vendors have opposed the idea of opening up interfaces to allow Open RAN deployment

Traditional (incumbent) vendors have so far opposed the idea of opening the interface to allow Open RAN deployment. However, they seem to be willing to open 5G interfaces, where they were opposed to open 4G ones. Since 5G deployment requires 4G equipment, operators are tied to using the same vendors for 5G as they have in place for 4G. The alternative is to replace all the equipment with solutions from alternative vendors, which would be costly.

But replacing all equipment with solutions from alternative vendors is costly for operators

And the cost of transition could be high. In the U.K., following the announcement from the U.K. government limiting the use of Chinese equipment vendors, BT announced that the cost of complying with the regulation could reach £500 million over five years, though the investment is likely to be front-end loaded. The cost of complying is not just in terms of the mobile network, but we would assume that mobile RAN replacement makes up the bulk of it. The cost is linked to the replacement of 4G equipment in order to be able to run both 4G and 5G with the same vendor. In a way, some of the replacement would have already happened but this decision forces that to accelerate.

And Then There is the Technology

- **Scale and Other Advantages for Incumbents:** Traditional vendor equipment may have some limitations in terms of agility and cost disadvantages but it is tried and tested and has over the years contributed to very stable networks. These vendors have experience working with multiple mobile network operators, have been at the center of the industry for a long time, and have significant scale. It's not just about the resources in terms of labs that differentiate these vendors but the active networks they run, information and solutions that can be developed with their networks, the other solutions and services they can deliver, and crucially the ability to test and improve the solution in real network conditions. Open RAN players may be getting their teeth into some of these contracts but not to the same scale.

- **Open RAN Is Still in Development:** Technology for Open RAN is developing fast and perhaps faster than anticipated a year or two ago. Today we are at the stage of live trials and limited commercial deployments in rural/sub-urban areas. We are yet to see a full commercial deployment at scale; outside of Japan and while established players may be keen to explore, there are still compromises to be made. For example, the solutions currently on Open RAN may deliver inferior performance due to the fact that it can support only previous versions of the technology at this point.

- **Benefits Take Time:** Software options and the overall ecosystem could be much more reliable over time and probably necessary to transition. But during the transition period, savings are likely to be offset by the investments needed to replace the components. We have seen this play out many times with operators investing in new systems (ICT investments). Eventually, the savings do kick in, but it usually takes time.

  – There is downside to the implementation of Open RAN versus having a purpose-built, fully-integrated, end-to-end RAN as it is supplied today. The purpose-built RAN could be more efficient in terms of power and size due to better optimization of functions versus a standardized generic processor.

  – The cost of an Open RAN platform could be higher initially. However, as the commercially off-the-shelf (COTS) hardware becomes more popular, the cost should come down due to scale.

- **Complexity Even More of an Issue with Multiple Vendors:** The purpose-built RAN will have the benefit of being fully tested, verified, and integrated by a trusted vendor, whereas the Open RAN network will require additional integration if the software and applications are from different providers. This will imply higher costs and there would be an inherent risk from working with new (and perhaps smaller) developers and vendors.

- **Time Not on MNOs' Side Given 5G Investments Are Due:** If mobile network operators had more time before 5G deployments were needed, it would have been possible to wait until some of these solutions improved. But the time for decisions for some relatively large-scale 5G deployments is now, so operators will need to rely on traditional vendors and architecture, where there is pressure to deploy.

State of Play: Early Stage but Developing Fast

Despite the obvious theoretical benefits of Open RAN, the cost of transitioning and the 'safety' of the known traditional vendor model mean a dramatic shift may not be imminent. There may be significant progress and rapid development, but we may not yet be at the tipping point. It is not a matter of things evolving in the right direction — that's happening — it is more a question of velocity. As with most things, ''People tend to overestimate what can be done in one year and to underestimate what can be done in five or ten years."

In this section, we discuss the progress that has been made so far, give examples of the initiatives that are in place, and lay out a roadmap for further development. Finally, we discuss potential catalysts that could accelerate the transition to Open RAN and significantly bring forward the benefits for mobile network operators.

Current State of Play

European telecoms have been actively involved in supporting the Open RAN movement, driving a period of unparalleled co-operation

European telecoms have been actively involved in supporting the Open RAN movement driving a period of unparalleled co-operation among the main mobile network operators. It's not just the fact they seem to be closing ranks on regulatory issues and co-investing more, there is also a clear focus for each of them to do their part to help the entire industry. A number of organizations have been formed by the main operators and some vendors, working together to bring Open RAN to life. TIP (Telecom Infra Project) and the O-RAN Alliance are the main ones.

The operators may have a powerful ally in their attempt to convince vendors to consider opening their interfaces — the European Commission and key member states. When the European Commission made a toolbox available for member states to deal with security, the main focus was on the power of the member states with a general stance on Chinese vendors. Each member state ultimately has enough discretion to reach its own assessment. One point stressed across the set of rules that make up the toolbox — perhaps even more universally — is the need for operators to limit their dependency on any given vendor and to have a diversity of suppliers at a national level. The medium-to-long-term mitigation plans are mainly focused on diversity in order to limit the risk of security issues in the first place, but also to ensure that any issues cannot just be limited but also dealt with.

Diversification of suppliers, sustainability, and the diversity of the 5G supply and value chain are key drivers behind the toolbox

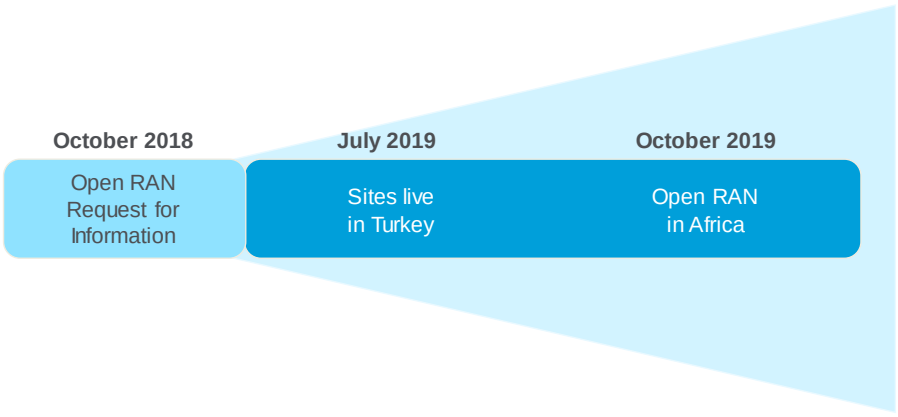
Without open interfaces, there will be limited choices in the medium term and no wide diversification of suppliers. But it also makes the dependency even more critical in the event that incidents do arise. When working with closed interfaces, it is almost impossible to switch suppliers in a timely manner, because it requires changing multiple components that are fully integrated. This could push governments to approve vendors under certain conditions, which could/should include open interfaces.

A roadmap for developing and deploying Open RAN technologies in multiple locations was first announced at the Telecom Infra Project Summit in November 2019. A request for information (RIF) was put for Europe (>100 sites) which represented a significant opportunity for Open RAN to scale.

In recent months, significant progress has been made in deploying live sites

In recent months, significant progress has been made with live sites being deployed in Turkey in July 2019 and Open RAN being introduced in Africa in 2019. Live trials are currently being conducted in Turkey, Democratic Republic of Congo, Mozambique, South Africa, and India and new trials have been launched in rural areas of the U.K. and Ireland. These trials are across all legacy technologies (i.e., 2G/3G/4G) and in Africa, the Middle East, and Asia Pacific, are covering a population of around 70,000 people with 25 macro sites on all existing technologies. The roadmap calls for deployment of Open RAN solutions in denser areas towards the end of 2020 and the launch of live pilots and commercial deployment in 2021.

Figure 26. From RFI to Live Trials

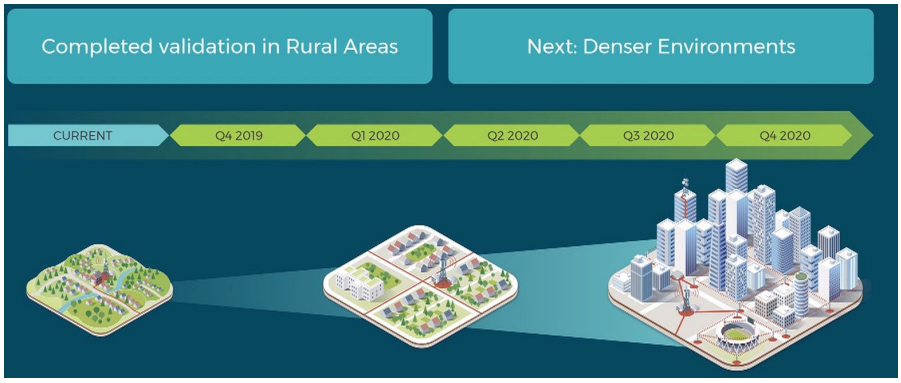


Source: Telecom Infra Project 2019

Initial trials for 5G started in rural areas, eventually moving to suburban and urban areas

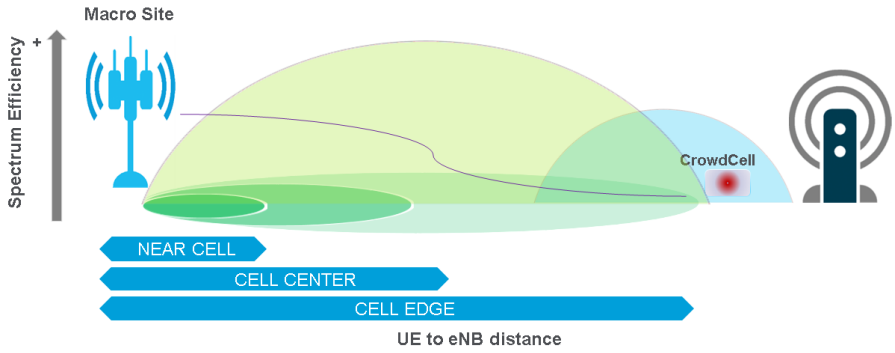
When it comes to 5G, some initial trials started in rural areas but the idea is to take them to suburban and urban areas. The request for information for 5G has already been completed, with a requirement for the partners to support the Open RAN specifications. There is still more to be done to reduce the cost of the hardware, which will happen with the acceleration of the development of white boxes.

Figure 27. Roadmap Aims to Develop Open RAN in Denser Areas in 2020



Source: Telecom Infra Project 2019

Figure 28. Open RAN Will Also Target Small Cell Networks



Source: Telecom Infra Project 2019

Current State of Affairs Around the World

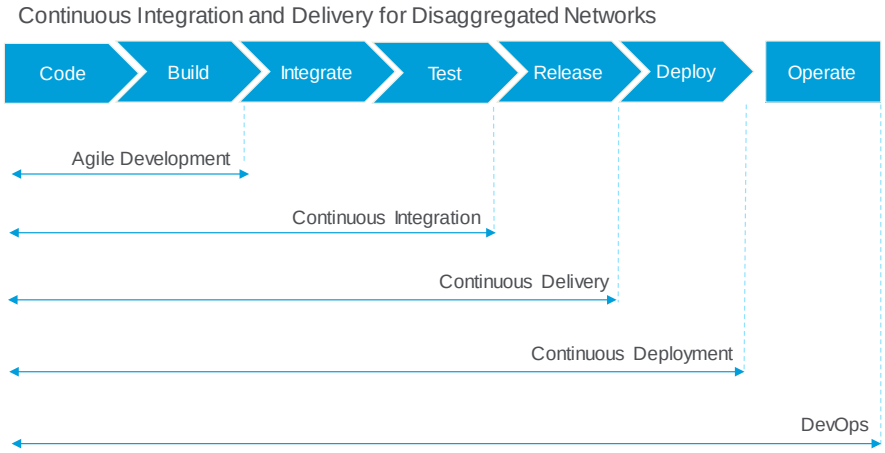
- **Still Limited in the U.S.:** Despite the outright ban on Chinese vendors, established mobile network operators in the U.S. are yet to undertake or announce any major initiatives on Open RAN. If the market does consolidate and an opportunity arises for a new entrant to roll out a network, that may well change. The risk/complexity of a greenfield project is far more limited and less costly. While at the same time, not having an established customer base (or having extensive roaming options, or both) can mean there is enough time to deal with teething problems

- **In Japan:** A new small player has so far emerged as the main champion of Open RAN. There are various reasons that have made this possible: the company has a background of disruption and innovation, which also allows for a different appetite for risk, it has a very small base, which makes deployment less risky, and it has no legacy infrastructure, reducing the need for expensive replacements.

- **In Europe:** There are currently only a few trials in the U.K. and Ireland deployed but these are limited to rural areas. However, there have been recent announcements from large European operators indicating they are extending Open RAN across their European footprint.

- **Little Traction in the Rest of Asia:** Early movers such as Korea, China, the Philippines, and Australia have built their networks using traditional network models where the network vendors provide radio equipment as well as the critical software needed to operate the system. Outside of Japan, no other Asian telecom operator has so far moved to build its network with an Open RAN system. Multiple Asian telecom operators however are engaged in testing the technology. There have also been multiple bans on Chinese vendors in Australia, New Zealand, Japan, and Taiwan, which may serve as a motivation to adopt Open RAN.

Figure 29. Benefits of Separating the Software



Source: Telecom Infra Project 2019

Open RAN Development

Uptake in rural and suburban areas is low hanging fruit in the development path for Open RAN

There is certain low hanging fruit in the development path for Open RAN, including uptake in rural and suburban areas. The fact that the technology may not be fully optimized or the latest version of the standard is less relevant and the pressure for operators to deliver maximum performance from the outset is much lower. In some of these areas, there are also no legacy 4G solutions with any given vendor implying a lack of significant upfront costs to replace the existing vendor. In addition, success in real world network deployments that TIP members have been running is reassuring.

It remains a difficult decision for operators to fully commit to Open RAN given the high and unpredictable upfront costs

There will also be selected areas, even in suburban and developed markets, where for tactical reasons, we believe that the main players in the industry (at least in Europe) will look at investing. But it remains a difficult decision for an operator to fully commit, particularly given the upfront costs of replacement are high, while the benefits will take some time to materialize. Instances where operators will need to replace their existing vendor could be interesting. We believe that if the operator isn't frontloading the replacement investment, then Open RAN vendors may be well placed to participate.

Over time we expect Open RAN to prevail but it could take time and accelerate when operators need to replace equipment

But that doesn't mean the role of Open RAN will not grow over time. As more networks are being developed and the technology matures, we believe the logical design of the network and the strategic alignment with what the customer (mobile network operators) wants will eventually prevail. However, this could take time and given the commitments the operators are currently making with existing vendors on 5G, the next chance for a wholesale shift may be when that equipment needs replacement. But the direction of travel should eventually take us there.

What Could Accelerate the Transition?

Having existing vendors agree to open the interface between the baseband and remote radio unit would accelerate the transition to Open RAN

The most obvious event to accelerate this transition would be if one or some of the existing vendors agree to open the interface between the BBU (baseband unit)-RRU (remote radio unit). That would effectively allow the mobile network operators to have control and introduce other vendors. Although traditional vendors don't necessarily have a single view on Open RAN, none of them appear willing (at least for now) to consider an open interface. A vendor will need to balance the opportunity to gain share or leverage other software features that operators may desire from third parties versus the risk of opening its own captive footprint to competition.

The uniting of the industry in alliance could also help persuade vendors to open the interfaces

What might persuade vendors to consider the transition to an open interface is the fact the industry seems to be uniting — via various alliances/groups and especially the O-RAN Alliance, which is setting the specifications. In any industry, if most of your customers are united in asking for something, it may be short-termist and damaging to keep them locked in; however attractive the barriers may appear.

Coming from another angle, we could see an acceleration if consolidation improves the scale and competencies of the Open RAN vendors. This could be through a number of them getting together or a major player taking an interest in backing them to expand into the RAN market.

Politicians pushing for the development of Open RAN could be another potential driver

Another potential driver would be if politicians push for the development of Open RAN vendors. The debate is so far more active in the U.S., where it has been openly discussed.

- In January 2020 a group of U.S. senators introduced a bill proposing more than $1 billion of investment into Open RAN development as an alternative to U.S. companies using Chinese equipment vendors. The funds would come from spectrum auction proceeds.
- Following this, on February 6, 2020, Attorney General William Barr suggested that the U.S. and its allies should consider acquiring a majority stake in a technology company to counteract the dominance of China, amid rising concerns on security issues. The White House later denied it was considering buying any company.

We believe both these stories show how sensitive the issue has become. Backing Open RAN could be a neat solution: A number of the new software vendors are based in the U.S., but crucially, a move to Open RAN could allow for other software vendors to develop over time. That could drive the impetus and exposure to scale deployments needed to drive the uptake of Open RAN.

U.S. 5G Deployments Apt to Test New Advances

5G is a different upgrade path than prior wireless technology upgrades and the U.S. wireless industry is about to test the network infrastructure with 5G deployments

Wireless companies across the globe are having trouble growing revenue. The U.S. is no different with wireless revenue growth recently recovering, but still underperforming nominal GDP. 5G is a different upgrade path than prior wireless technology upgrades, because faster speeds generally depend on the deployment of larger blocks of spectrum, new antenna technologies, and core network upgrades. In return, carriers can slice a 5G network into different use cases by customer verticals, applications, and geographies to offer a combination of enhanced mobile, fixed wireless broadband, and IoT/business-to-business (B2B) services.

The U.S. wireless industry is about to test the advances for wireless network infrastructure with ongoing 5G deployments by the three surviving national wireless carriers in a deal scenario, which is preparing to enter the industry as part of the concessions related to the proposed merger.

For the existing wireless carriers, the separation of hardware and software within the wireless networks could open the door to greater competition in the network infrastructure market and lead to opportunities for each of the carriers to try to add some degree of differentiation on commoditized hardware.

One company recently discussed on its quarterly earnings call the opportunities to reduce build and maintenance costs by leveraging new software capabilities from virtualization and Open RAN to significantly improve the automation associated with network fine-tuning, enhancements, and troubleshooting.

5G needs a lot more spectrum to achieve the faster speeds that it promises

The consensus is that each next generation of wireless technology provides a better and faster mobile experience for users on the existing spectrum bands. 5G is different, because speed and capacity benefits on most of the existing mobile bands from 4G to 5G are fairly limited. Instead, 5G needs a lot more spectrum to achieve the faster speeds promised by the 5G marketing materials.

But this spectrum is in higher-frequency bands with limited propagation, which may curtail its use

Unfortunately, the amount of spectrum needed to provide the true benefits of 5G is only available on higher-frequency spectrum bands (mmWave). Higher frequency spectrum generally has limited propagation (i.e., reach and in-building penetration). This may limit the use of high-band millimeter wave spectrum to targeted outdoor coverage areas, venues, and fixed wireless broadband.

As a result, there is no compelling reason for carriers to rip and replace 4G for 5G over the next five years. Network slicing means that 5G networks can be used to mass-customize experience across verticals and applications. In the process, the same 5G network enables three key opportunities:

- Enhance mobile with speed boosts of up to 15-20% and potentially offer service tiers based on good, better, best speeds;
- Fixed wireless broadband services to homes and business locations, albeit potentially with an external antenna; and
- Create wireless solutions for enterprise customers by better enabling machine-to-machine communications & broader Internet-of-Things, such as Smart Grid and Smart Driving.

Asia Network Builds

5G is in its infancy in Asia outside of Japan, which has started trials and is expected to launch commercially in April 2020

5G remains in its infancy for most Asian telecom operators and has launched commercially in Korea, China, the Philippines and Australia, with a carrier in Japan announcing the launch of 5G wireless services on March 26 in 15 prefectures. Builds for the rest of Asia, however, remain slow with network strategies yet to be even defined. Taiwan, Hong Kong, Thailand, Singapore, and Malaysia are expected to launch 5G networks by end 2020/mid 2021 with build-outs yet to be established. Larger markets such as India and Indonesia are likely to be pushed out even further towards mid 2020/end 2021

Network builds for early movers still lean on traditional network models where software is bundled with equipment. Early movers such as Korea, China, the Philippines, and Australia have built their networks using traditional network models wherein the network vendors provide radio equipment as well as the critical software needed to operate the system. Outside Japan, no other Asian telecom operator has so far moved to build its network with Open RAN systems. Multiple Asian telco operators however are engaged in testing Open RAN and many are members of the O-RAN Alliance; however, we have yet to see any commitments to adopt such a model.

One Japanese company has sidestepped the traditional network models in order to deliver a lower-cost innovative system using smaller cloud-native software companies and processing functions at edge computing sites

Japan is leading the pack in Open RAN adoption in Asia. One Japanese company has taken an aggressive step towards its greenfield network build-out and sidestepped some of the traditional network models to deliver a lower-cost, innovative system approach. To start, the network will be fully virtualized with many processing functions performed at edge computing sites. In addition, software architecture has been provided by smaller cloud-native software companies instead of traditional vendor bundled software from incumbent network vendors and network trials are now underway. Admittedly, the network build-out has been more difficult than expected and has resulted in significant delays. Commercial launch was initially targeted for October 2019 but has since been pushed back to April 2020. Network testing is however ongoing and trial users have expanded from 5,000 initially to 20,000.

Network vendor limitations opened the door for Open RAN but there were few takers. Some Asian markets have pushed for network vendor restrictions with regard to 5G, citing security concerns. Australia, New Zealand, Japan, and Taiwan have imposed a full ban on Chinese equipment for 5G networks, creating specific challenges towards 5G migration as some 4G networks in these markets are already running on Chinese equipment. As such, a network ban would impact their ability to switch to 5G on a ‘no-strings attached-basis’ and co-utilize some of the existing active network elements. One Australian company cited its decision to exit its planned network roll-out following the decision by the Australian Competition and Consumer Commission (ACCC) to block Chinese equipment vendors. This resulted in a partial write-down on earlier investments.

The exclusion of key vendors in the 5G roll-out could accelerate Open RAN adoption

It is also worth noting that the exclusion of key vendors could have served to open the door to and accelerate Open RAN adoption as it pushes telecom operators to rethink their network position with more limited options in the market. However, few operators have taken that route so far, with only one small operator in Japan willing to engage in a move towards Open RAN systems. Most Asian telecoms are taking a more conservative approach, with ongoing concerns on potential disruptions which can occur with Open RAN.

Interview with Vodafone: Santiago Tenorio

Santiago Tenorio
Head of Network Strategy
Vodafone and Board Member at Telecom Infra Project (TIP)

You have already moved to a fully virtualized core network — what was the rationale and key learnings?

The move to virtualization was necessary as appliances won't scale well. Traffic is booming and growing exponentially, and it is not slowing down but is accelerating. Staying with isolated appliances to cope with that traffic was not the way forward as appliances are not efficient in coping with this growth. With virtualization we can have a generic CPU bulk procured from a specific vendor (which is much more economical) and have better abilities to scale through pooling and shared resources. We can achieve important synergies by using the same infrastructure on different network functions, which is more efficient and more scalable. We have already gone through the process of virtualizing the whole core network and making it cloud native and it's working really well.

What are the main benefits from virtualization?

One benefit is, as I mentioned, scaling up and capacity.

But there are other interesting operational benefits. You can resolve problems in the network and restore the service more quickly and smoothly. If you have a problem with a CPU in a virtualized infrastructure, the impact is automatically mitigated. If you run on appliances instead, you would have to replace the appliance or fall back to a resilient unit. On virtualized/cloud networks you can create an instance of the same software elsewhere while you fix the issue so you preserve the services with minimal disruption. You can also allocate capacity as you need it and scale it up and down automatically depending on demand.

Operationally, virtual networks are more efficient. Virtualization will also enable more advanced functions like low latency and edge computing that wouldn't even exist in the world of appliances. In the world of appliances, you would need to create all the functions, products, and services in every site in case someone uses it — it would be impossible. Multi-access edge computing, or MEC (edge core), which is used for low latency, only exists after virtualization. You can create an instance of a network function instantly wherever demand exists and when that user moves or the demand disappears the entire virtual function gets dismantled.

Are virtualization and Open RAN needed for 5G?

Not necessarily — there is no pre-requirement for 5G, but 5G was born in a virtualized, cloud-native world. In theory, you could have developed 5G in appliances to a point but it wouldn't make sense when we have already evolved to the cloud. It is not that virtualization was a pre-requirement, they are fairly independent, but 5G is cloud based because of the developments we have made so far and makes use of all good things that virtualization brings, natively.

When it comes to the access network, the Open RAN movement started in 2G, 3G, and 4G and there is nothing yet fully ready for 5G so Open RAN and 5G are also independent, albeit happening in similar timeframes.

Are there links and synergies between virtualizing the core, virtualizing the RAN, and Open RAN?

The three are separate and independent. There are some synergies to the extent that an operator who has invested in virtualizing the core, has gained all the know-how, and has reached the right contracts with suppliers, could use some of these capabilities to virtualize the RAN. However, the software for the core and the RAN might not be the same or the equipment needed may not be in the optimal locations to be used by the RAN so there are limited synergies from shared resources.

It's worth highlighting that one of the key pre-requisites for virtualization of the RAN is the abundance of inexpensive fiber. If there is no economical way to lay multiple fibers to access network sites then it may not make sense economically to virtualize it in a centralized manner because the efficiencies won't be meaningful. In some scenarios, the fiber and the optical equipment may cost you more than the benefits from V-RAN.

Our focus on the RAN remains in delivering Open RAN, regardless of the RAN virtualization which we may want to do opportunistically, while at the same time we've been championing the move of the core to cloud native.

Are there any instances where you could opt for Open RAN without virtualizing it?

Yes, without doubt. Lack of consistently abundant inexpensive fiber will make the economics of virtualizing the RAN not so attractive, while the principles why you want to open the RAN are still fully valid.

Of course on a Virtualized RAN there are benefits from pooling all the basebands together. Synchronizing your base stations is an interesting concept that has real benefits. When you have all the resources synchronized you can start doing more interesting things and manage the network with a broader perspective, but you can actually do this onsite to a large extent too — you don't need to virtualize the access to synchronize it. You can have a software that makes all base stations talk to each other without centralizing the 'brain' — this is called distributed RAN and we have been championing this for a few years.

What are the motivations for moving to Open RAN and what has been the evolution?

When Huawei was introduced by the major mobile network operators in the European Union, the total cost of owning your network started to come down more quickly than it had done before. The main driver for that was the accelerated pace of continuous innovation on top of more aggressive commercial competition amongst the players of course. This effect lasted for 6-7 years driven mainly by the effect of the technology innovation itself leading to better performing, more efficient kit — not just by the increased commercial competition.

Eventually, a status quo was reached again and the pace of innovation returned to normal and slowed down again. So we (the operators) started to search for the next big thing, the next wave in the race for innovation. None of the traditional vendors seemed to be in a position to be the champion for that new wave in the same way that Huawei was at the time. Some had the R&D credentials but not the scale or the commercial appetite, while some were extremely hungry but short of disruptive innovation ideas. They all do an amazing job, but all-in-all no one seems quite ready to become the new vector of a wave for disruptive innovation as the one we saw in the past.

Four years ago we realized that if there was to be a new disruption to speed up performance and efficiency, chances are it was going to be Open RAN. Flexible, cost efficient, and open where you can tap into multiple companies all extremely hungry and with an aggressive approach to innovation. We think this concept may have the potential to create the new wave of technology acceleration that could eventually throw us into a new cycle of increased performance and efficiency for perhaps another 6-7 years if we do it really well.

What is the main hurdle to fully deploy Open RAN?

One obvious problem is that Open RAN may not come from established players initially, as incumbent vendors may not necessarily want to open the interfaces to all others. Hence, deploying Open RAN is likely to be based on alternative solution rather than a roll out on top of existing kit or smoothly introduced starting from an incumbent kit, at least initially.

Under Open RAN, the radio hardware would be able to connect to and to run software from different/multiple vendors and the CPU/baseband will be generic as well. The problem with this so far of course is that even if the interface is open, when you move to generic CPUs in principle you lose the edge from ad hoc accelerators and you may compromise on resulting performance or capacity versus traditional solutions. However, on the one hand, past 3GPP releases may not need any hardware acceleration to run uncompromised as CPU performance has already caught up with them, and for state of the art releases (e.g., 5G), latest developments are making progress on performance and we may get to a point where we no longer need hardware acceleration or see compromises versus traditional solutions.

How can you overcome these hurdles?

We believe this has to be an industry movement. If all operators join forces and drive in the same specification, we can speed up Open RAN feasibility. Organizations like TIP and the O-RAN Alliance have a key role to play and have already proven to be very effective in making Open RAN a reality.

Do you think you can move to a full commercial deployment or it is still too risky to deploy it to the entire customer base?

I think we are ready to start in the more rural areas and we may be able to move smoothly to the more dense ones soon. We have completed trials in India and Turkey. We are now rolling out in moderate scale in rural areas of the U.K. and Ireland. It won't be too long until we can start testing in dense urban areas. When and whether we'll see Open RAN as a full alternative equivalent to what incumbent vendors can deliver now, time will tell.

Figure 30. From Trials in Rural Areas to Dense Urban Areas

Source: telecominfraproject.com

Figure 31. Vodafone has Invited Open RAN Vendors to Bid in its EU RAN Tenders

Source: telecominfraproject.com

What changes will Open RAN bring to your business model?

I believe it is well in line with our ambition to become a Tech Comms company or Technology Communications company. We may want to take the role of delivering a smooth integration between software and hardware from different vendors ourselves. We may want to drive much more closely the specification of what we want, including delivering our own hardware designs. We may even consider developing critical parts of the software that runs in the base station.

What would be the main application or differentiating factor of Open RAN?

One differentiating factor would be coverage. Open RAN may make economic deployments that today are unaffordable because of its lower cost to own. If successful, in the mid to long term, Open RAN could have developed to a point to make a difference in some areas of 5G performance versus traditional solutions and be competing through intelligence built on top.

Interview with Telecom Infra Project (TIP): Vish Mathur

Vish Mathur
Global Head of Engagement
Telecom Infra Project (TIP)

Launched in February 2016, TIP is a collaborative telecom community that is evolving the infrastructure underpinning global connectivity. We believe accelerating innovation, coupled with new business approaches and cost efficiencies, will help the industry build the networks of the future and create business opportunities for new and existing companies alike.

TIP exists as an independent global association with over 500 members and a Board of Directors, chaired by Vodafone, including Deutsche Telekom, Telefónica, Intel, and Facebook.

TIP has Three Main Missions and Priorities:

- **Build, Test & Deploy Next Generation Network Solutions:** The TIP community collaborates on development, test, and deployment of open and disaggregated end-to-end solutions which meet a market need — for example urban densification within smart city or urban connectivity programs, rural connectivity in underserved and poorly connected geographies, or private enterprise networks.

  TIP's approach is to leverage unified and standardized reference designs to develop, harden, and scale deployment of telecom network solutions, which are based on lower cost, general-purpose, vendor-neutral commercial off-the-shelf (COTS) hardware with software defined technology built on top. These offer choice and control back to operators, breaking them out of proprietary vendor solution arrangements, and allowing them to work in multi-vendor environments.

- **Deliver through Collaboration:** This approach requires a model of collaboration which is unique to TIP. No other organization is doing this, in this way.

- **Expand the Telecom Supply Ecosystem:** Disaggregation of hardware and software components across Access, Backhaul, and Core networks, means TIP plays a key role in facilitating the collaboration between a more open and diverse, innovative, and interoperable supply chain. Within this expanded ecosystem, re-aggregation, integration, and management of disaggregated network elements become a vital component of the TIP value proposition.

How did TIP get involved in the development of Open RAN and what are some of its key milestones in development?

The idea of Open RAN has been discussed for quite some time in the industry, but it has only really been in the last few years that we have seen Open RAN technology being tested and deployed in several markets. Open RAN technology has been TIP-incubated since 2017.

In 2018, a joint request for information (RFI) was submitted by two of TIP's founding members, requesting the vendor community build an Open RAN 2G/3G/4G solution set built on general-purpose vendor-neutral hardware and software-defined technology, which can be tested in lab environments and in rural and urban field trials.

In November 2019, one member announced they had successfully deployed 2G/3G/4G Open RAN across 25 macro sites in Turkey, with technical performance on par with expected RAN key performance indicators (KPIs), and continuing with similar deployments in Europe. On the back of these successful trials, Vodafone announced they were opening for tender Open RAN deployments across their European and African footprint (~100,000 sites across 14 countries).

The other member announced they had launched commercial deployments of Open RAN in Peru as part of 'Internet para Todos', a collaborative project between operators, banks, and communities to develop an open access wholesale rural mobile infrastructure which aims to connect the unconnected in Latin America with ambitions to provide LTE coverage to over 6 million people by 2023.

Beyond these founding members, we have seen other operators kick off their own Open RAN trials and deployments, which gives the TIP supply ecosystem the confidence and rationale to continue to evolve the Open RAN product.

The O-RAN Alliance was also formed by a set of Tier 1 operators and vendors and has a specific objective to define technical specifications for Open RAN 4G and 5G solution development. As of February 2020, TIP and O-RAN Alliance have set up a cooperation to design, build, test, and deploy Open RAN 5G solutions, which reference O-RAN Alliance technical specifications.

How do community labs work? Any tangible examples of how that accelerates the development?

TIP currently has 13 community labs around the world. These labs are state-of-the-art facilities designed to support the diverse ecosystem involved in product and interoperability testing.

The TIP Community Labs are a resource for TIP project groups to advance solutions being developed and designed. Lab activities/projects need to be sponsored by a TIP Project Group (PG) and approved by TIP Technical Committee. Any member of the TIP community can engage with these projects and provide solutions or expertise and any member of the community can use the TIP Community Lab as part of these approved projects.

At the 2019 TIP Summit, TIP Continuous Integration and Continuous Deployment (CI/CD) software labs were launched in North Los Angeles and Madrid respectively. Embracing an agile DevOps methodology, these labs are building the skills and processes to enable the TIP ecosystem to remotely manage and upgrade TIP solutions in the field. Sprint also announced the opening of a TIP Community Lab focused on Open RAN 5G NR in Overland Park, Kansas.

How did engagement change over time (recent developments and progress)?

TIP has grown from 30 members in 2016 to over 500 in 2019, with 13 community labs across the world and potentially more in the near future

In November 2019 we launched TIP Exchange, a new marketplace designed to help industry players find products and solutions validated by the TIP community, featuring 45 solutions from 28 TIP members. TIP Exchange distills TIP-qualified offerings so that TIP members can showcase their products and solutions, and service providers can easily evaluate technology and technology partnerships for flexible and innovative connectivity solutions.

What are you experiencing in terms of engagement from other players in the industry?

From TIP to the O-RAN Alliance and others, there is a broad engagement on this area from across the industry — particularly from MNOs. The number of industry initiatives focused on open and/or virtualized RAN certainly demonstrate the industry's interest in these technologies and also their significance. We are currently talking to other groups to explore areas of common interest and finding ways to collaborate.

Outside of RAN, can you give us examples of progress in disaggregation?

TIP has growing demand for disaggregated solutions with the Transport backbone as well. These allow for lower COTS hardware, software defined platforms, and harmonized data planes. This includes Disaggregated Cell Site Gateway (a 4G and 5G ready disaggregated ethernet router that connected multiple cell sites into the backhaul) and Cassini (an optical transponder which converts ethernet traffic into optical dense wavelength division multiplexing, or DWDM). We are continuing to see innovation in the Optical Transport space with development of standardized software-defined network (SDN) Controller solutions, and harmonized data sets.

New solutions are also emerging and new TIP Programmes have been set up within the Network Management space, Open Core, and Network Security domains.

Interview with Orange: Yves Bellego

Yves Bellego
Director of Network Strategy
Orange and Member of O-RAN Alliance

As a member of the O-RAN Alliance, could you please explain the purpose of O-RAN Alliance and your involvement?

We are one of the founding members of O-RAN Alliance because we felt there was a need for such a body to define the new architecture for the radio. Our goal with O-RAN is mainly to define open interfaces. We expect to have a RAN that is not a big block but open interfaces so that we can have different elements which can be sourced by different vendors. So far, we have to buy the whole RAN from a single vendor and that is what we want to change.

We now have the first specification of open interfaces established by O-RAN. The aim is to have the interface between the remote radio unit (RRU) and the baseband unit (BBU) fully standardized and open so we can add different suppliers. We are also working on testing integration because if we are going to use different vendors we have to integrate them all. The work will be on open source to help companies test their own solutions.

The Third Generation Partnership Project (3GPP) had a definition that was meant to be open and was meant to allow operators to deploy 5G as an overlay on a 4G network, but in practice it didn't work. It was not sufficient. Today we cannot fully deploy 5G on an overlay network. This is why we pushed for Open RAN and we believe we would have these specifications in the next year or so.

What are the benefits of Open RAN?

Today, we have baseband, antennas, and all the radio equipment from the same supplier. In the future we will continue to upgrade our networks and will add 5G capabilities to our networks, like cloud edge. For this, we want to have the flexibility to change just the radio or to upgrade only part of the network, for instance, without having to change all of the RAN in one go. We also want to have more flexibility in the type of services and configuration we provide as we believe this will give us capabilities which allow us to differentiate.

Today we are restricted by the choices of our vendors. We have ideas we would like to implement and differentiate from our competitors but at the moment we are a bit limited.

Our aim is not to move away from traditional vendors, but to have more options so that we can source from different suppliers. We want to avoid being forced to do everything with one single vendor; we want to keep the door open to other vendors and new comers.

Could you achieve this without vendors opening up the interface?

In Open RAN our goal is to convince the vendors to accept open interfaces so we can buy the baseband from a different vendor to the one that supplies our radio unit, similar to how today we buy the radio network from a different supplier from the core network.

The way to get vendors to open the interface is by having enough power, which is why it is important to not do this alone. The O-RAN Alliance has been created by several operators and we are working on getting more and more operators to support the initiative.

How do you see 5G deployment happening in Open RAN if vendors do not open the interface?

Realistically, we think the first phase of 5G will occur in the same way we are doing our initial deployment, where the RAN is not open. However, we see the opportunity to upgrade the radio in the future in our European network without touching the rest of the system which is from another vendor.

The initial 5G deployment is not relevant for Open RAN because the Open RAN solution for 5G is not yet available. In the case of Orange, 5G in Open RAN would make sense in Africa and APAC but not yet, and there is no clear plan for this now.

Other carriers like Vodafone are running trials in rural areas — where do you stand on this?

Vodafone is doing something from TIP specifications which is different to the O-RAN Alliance. We are doing something similar in Africa but this is separate because the main objective here is to save on costs and the RAN is not virtualized. The main purpose is to get the cost as low as possible. This is different to what we are trying to do in O-RAN Alliance.

What will be the main differentiating factors in the future? Is there room to have a bigger role in the IoT ecosystem than just providing connectivity?

That is the main idea — Open RAN will give us flexibility to define how the network will be for our business-to-business (B2B) customers for instance. Network slicing will give us more flexibility to design the slices and the level of quality of service we deliver in each slice. This will help us differentiate from our competitors.

How far are you in the process of virtualizing the Core Network?

We need to separately address the enterprise market, where virtualization and software defined networks are a reality now, and the residential market where virtualization is in progress.

On V-RAN, a key question is where the intelligence lies. How is this addressed in Open RAN specifications?

In the past we let the vendor decide where to position the intelligence and each vendor could optimize it. When we specify the location we ‘freeze’ it in a way so we have to be cautious about it. This is one of the reasons why the O-RAN specification takes time, as we need to discuss this with vendors. We have no strong preference at this stage on the location of the intelligence but we need to anticipate what will come next, like edge computing for instance.

Is innovation slowing down as a result of a concentrated vendor industry?

I wouldn’t say there is slowdown in innovation as our networks are evolving every day and many things are happening. But we are missing openness, we need to keep it as a competitive environment where we are not locked in with one vendor.

Why are Open RAN technologies lagging behind fully integrated solutions?

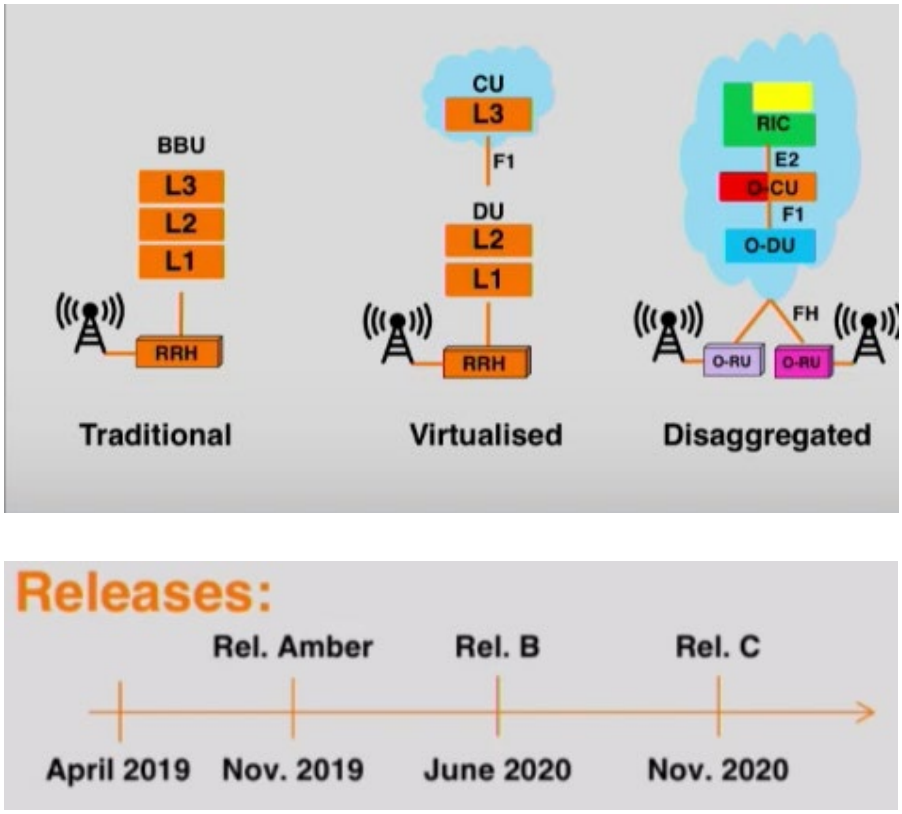
The argument from a vendor perspective is that by complying with Open RAN specifications or with open interfaces it takes them more time, and therefore they cannot provide the latest technologies under Open RAN specifications. We are trying to factor the time between technologies being released and when they can be open.

For new vendors, the incentive is not to join in the full radio network but to join just in one smaller part where they can be experts, so they are not racing to get the latest technologies at this point in time.

Would you virtualize the RAN in your entire network or would you choose not to do it in some areas?

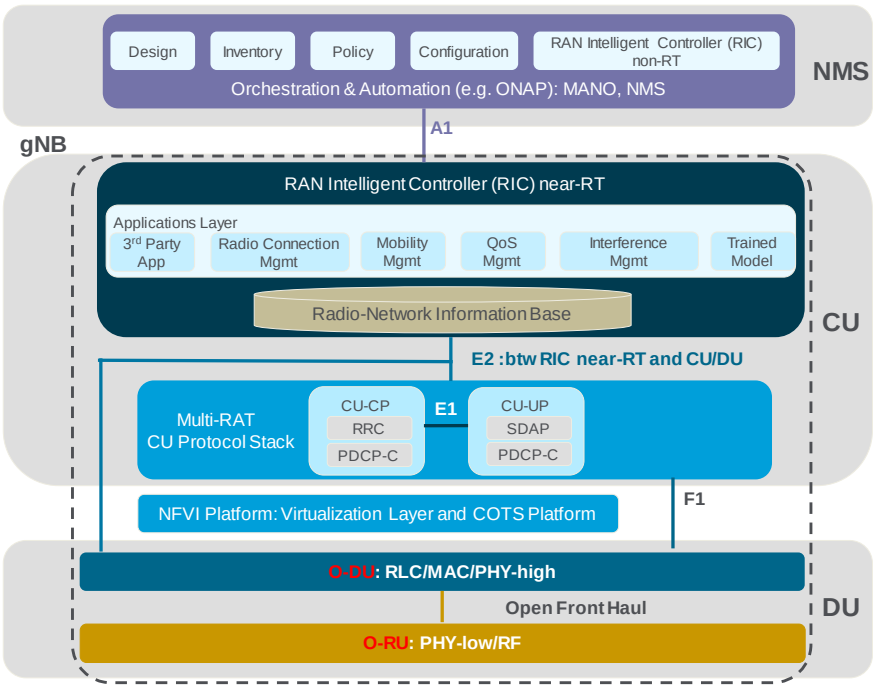
This is a complex question and we do not have an answer yet. We tested V-RAN and until now there isn't a compelling benefit to do it at large scale. So far the economics do not justify it. But, we still don't have the full roadmap for the virtualization of the RAN.

Figure 32. From Traditional RAN to Open RAN



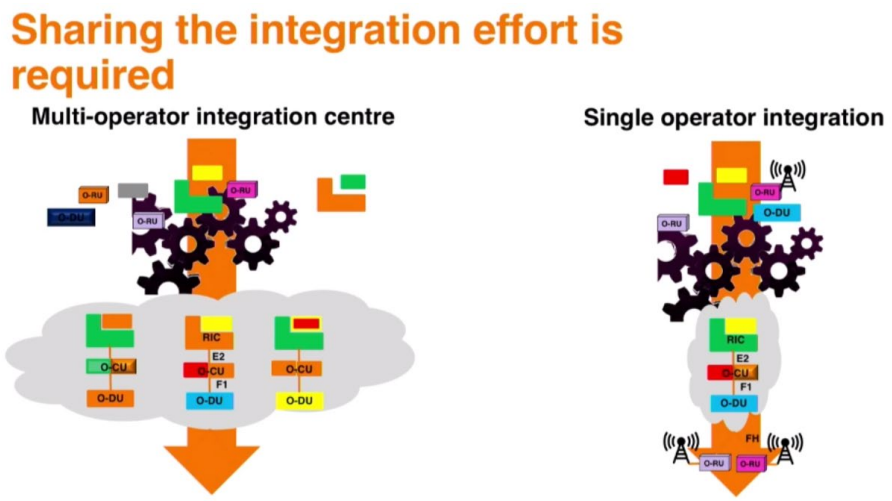
Source: Citi Research

Figure 33. O-RAN and 3GPP Architectures



Note: 3GPP Network Elements = Network Management System (NMS), Centralized Unit (CU), and Distributed Unit (DU).
Source: Orange

Figure 34. Sharing the Integration Effort



Source: Orange

Interview with Altiostar: Shabbir A. Banasrawala

Shabbir A. Banasrawala
Head of Product-Go-To-Market
Altiostar Networks, Inc.

A brief history of Altiostar and how Open RAN has been core to its strategy

When Altiostar started its journey, the RAN industry was focused on providing coverage for mobile network operators (MNOs) targeting voice and data applications. Cloud-based technologies that were previously adopted in the IT industry were slowly gaining traction in the telecom sector as a means to disaggregate the hardware from the software, virtualizing and cloudifying the software with open standards, and increase the overall innovation to the network.

We were the first company that split the radio protocol stack into real-time versus non real-time functions to deploy RAN functions across various edge locations, thus laying the foundation for an open disaggregated virtualized RAN. The next stage of this product evolution was working very closely with many Tier-1 MNOs to test and harden the solution for various deployment and traffic models to give them the confidence to consider this new paradigm for adoption in a large-scale deployment. A lot of what we did as part of this journey has now shaped and contributed to what we call open virtualized RAN.

What were the main lessons learned from the Rakuten Japan deployment?

When Rakuten announced it would be deploying an end-to-end cloud-based mobile network across Japan, which would also include an Altiostar open virtualized RAN, this surprised everyone because at the time they were the first mobile network operator committing to deploying its network with this new paradigm. Rakuten's intent was to leverage different vendors for the radio, orchestrator, network function virtualization infrastructure (NFVI), and management layer. This had not been done before.

What was intriguing about this announcement is how Rakuten managed to bring together this wide-ranging collection of vendors and the commitment Rakuten had made to deploy this at a scale unseen before. In turn Rakuten was in the driver's seat where they introduced various industry firsts while ensuring control of the different modules used to build this network.

In addition to this, since Japan as a culture has a high focus on quality and we knew our solution would be used as the fabric in a variety of deployment models including macro and small cells in both 4G and 5G, we had to not only establish the different interfaces across different components, but we also took responsibility on behalf of Rakuten to extensively test and harden the solution to ensure reliability.

What are the main challenges for Open RAN now?

Going through the different waves of new innovation, we know there will be challenges as the paradigm takes shape. This is the case for Open RAN as well. However, from the experience we have in Japan as well as with other operators in different geographies, we now know this technology is not only viable but also something that can be done at a large scale.

Mobile network operators have now started to recognize that Open RAN, as well as cloud technologies, will provide them with the platform to deploy new applications and services. For the adoption of this transformational change to pick up pace, operators need to commit to open technologies with actual commercial deployments to help build the ecosystem.

The new Open RAN vendors need this sort of commitment to ensure that the technology can be built and hardened with a unifying goal of deploying a commercial network.

Can you do Open RAN without abundance of fiber, like in Europe where fiber availability is limited?

We are already working with multiple operators and industry leaders where the availability of fiber is limited and have done extensive testing of our solution with a variety of transport options. A good example is the work that we are doing with one operator in Europe to validate this in different geographies. To this effect, Altiostar has developed multiple deployment architectures which allow mobile network operators to leverage cloud technologies and the corresponding benefits like automation and scalability across both urban and rural areas.

What can Open RAN bring to the customer that the traditional model can't? Is there enough of an incentive to overcome the reluctance to 'take risks'?

Open RAN as a concept has multiple benefits that include modularity of RAN functions, disaggregating the hardware from the software, enabling a new ecosystem driving innovation, and lowering costs. The disaggregation which began with the hardware is now going further where Open RAN is also being considered as a means to introduce new algorithms, applications, and micro-services within the software stack. We are already seeing this being played out where innovation is being unleashed through global non-traditional telecom companies who are offering solutions to operators.

As the traditional vendors consolidate and data gets commoditized, operators today have to consider the implications of not controlling their destiny. The industry today needs Open RAN to introduce not only a new paradigm but also bring diversity in the supply chain. Operators who are looking to make the transition to Open RAN can mitigate this risk by finding a region to begin deployments and then expand it across their network further. But it is important that operators begin adopting this mindset change as they make investments into future deployments so that they can control their own destiny in light of the consolidation that is happening.

Why are 5G solutions in Open RAN falling behind?

I wouldn't say that they are falling behind. 5G is in fact the best place to adopt Open RAN by virtue of how it is being defined. As an example, we announced we are launching 5G with Rakuten using cloud-native containerized network functions which will run on general-purpose servers powered by Intel technology. This solution has the capability to not only offer control plane and user plane separation but also allows operators to utilize them for deploying microservices and scale them according to the different types of traffic profile. We are talking about network slices that can evolve based on the type of application being used. This is the platform that operators want to adopt so that the true potential of 5G can be realized.

Are you seeing more willingness from operators to try the solutions now?

Open RAN is definitely now being more widely accepted beyond a marketing angle by some industry thought leaders. Operators are realizing this is not just about lowering costs but about a transformational change in the way they operate a network. As mentioned earlier, the leadership and commitment from Rakuten was the spark that inspired this change in the industry.

Could governments intervene to accelerate Open RAN adoption?

Yes – this is very relevant considering the debates that are currently happening in the U.S. and now globally. If networks were built keeping modularity in mind, introducing new technology or a vendor or a new service would not have such large cost implications for operators, especially rural ones. The dependency on one vendor creates a lock-in on critical service that impacts so many people.

Another consideration is the traditional networks being deployed today are black boxes in the sense that they are closed proprietary implementations. Open RAN has the potential of bringing transparency in terms of open interfaces, disaggregation of hardware from software, and better vulnerability testing of the different modules.

Finally layers of cloud security technologies in private and public clouds that are well established in the financial and government domains can be incorporated into mobile infrastructure.

O-RAN Alliance

The O-RAN Alliance comprises 22 operators globally (including Verizon, Softbank, Telefónica and China Mobile, among others) and a large number of contributors (including vendors like Altiostar and ZTE) which together are working on the evolution of the radio access network around the world. The alliance was founded by operators aiming to define clear specifications and build a supply ecosystem that allows them to evolve the RAN networks towards openness and intelligence.

"Our industry is approaching an inflection point, where increasing infrastructure virtualization will combine with embedded intelligence to deliver more agile services and advanced capabilities to our customers. The O-RAN Alliance is at the forefront of defining the next generation RAN architecture for this transformation."

— Andre Fuetsch, CTO and President AT&T Labs

According to the O-RAN Alliance, the future RANs will comprise white-box hardware, virtualized components, and a standardized interface which supports the principles of intelligence and openness. Openness means the interface allows for smaller vendors and operators to introduce their own services and customize the network. Intelligence means the networks will be able to automate operational functions using deep learning techniques, thereby reducing the need for human intervention.

Organization

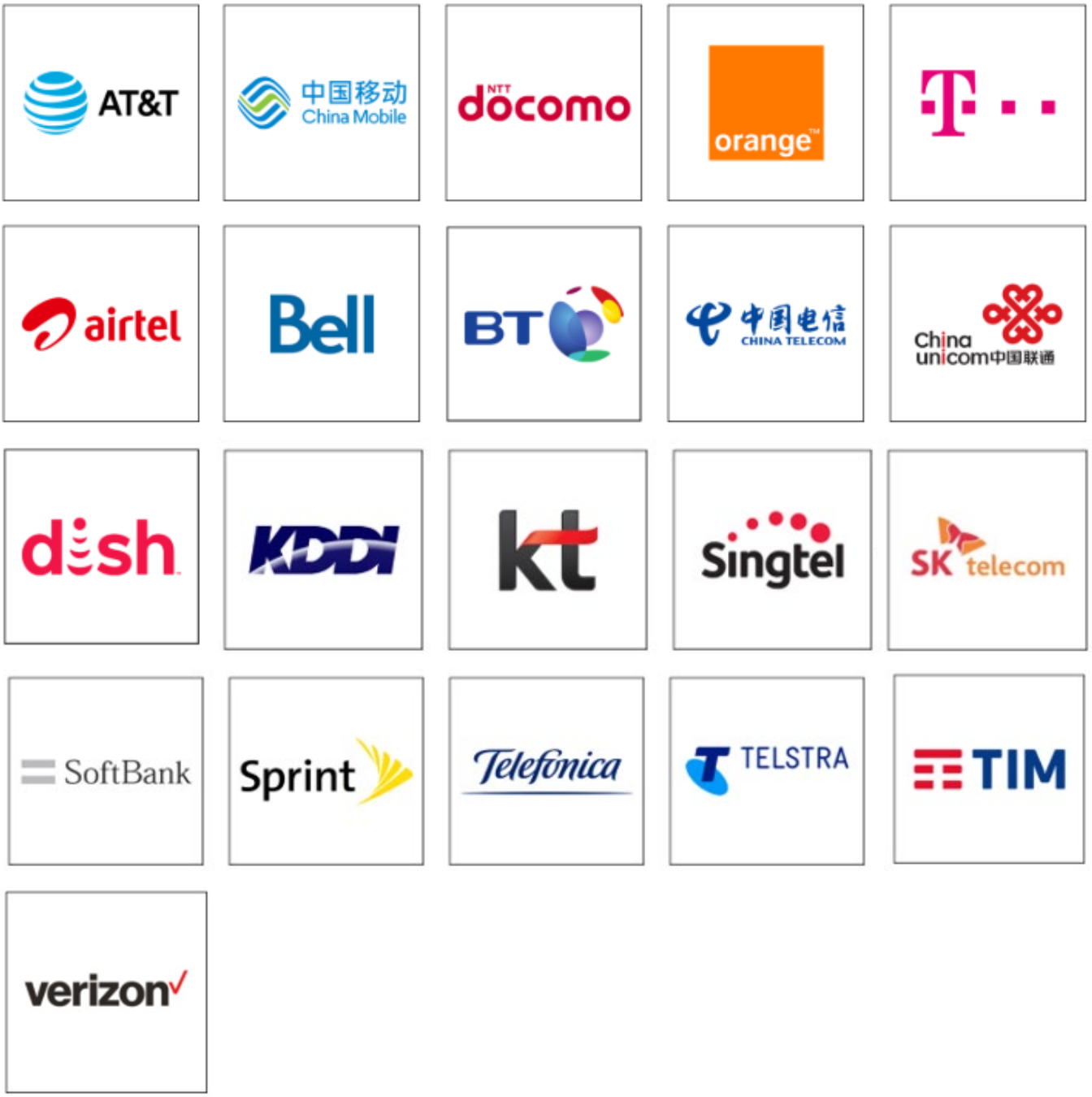
The O-RAN Alliance was founded 2018 by AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO and Orange. It has an Operating Board formed by 15 operators and a Technical Steering Committee (TSC). There are eight technical working groups with specific focus areas within the specification work — all members and contributors can participate in these working groups:

- WG1: Use Cases and Overall Architecture Workgroup
- WG2: The Non-real-time RAN Intelligent Controller and A1 Interface Workgroup.
- WG3: The Near-real-time RIC and E2 Interface Workgroup.
- WG4: The Open Fronthaul Interfaces Workgroup.
- WG5: The Open F1/W1/E1/X2/Xn Interface Workgroup.
- WG6: The Cloudification and Orchestration Workgroup.
- WG7: The White-box Hardware Workgroup.
- WG8: Stack Reference Design Workgroup

The O-RAN Software community is a collaboration between the O-RAN Alliance and Linux Foundation to support the development of software compatible with the O-RAN Alliance's open architecture and specifications.

Currently, there are two working projects, one to implement the O-RAN specification in Open Source and one that will acknowledge essential patents.

Figure 35. O-RAN Alliance Operator Members



Source: www.o-ran.org

Interview with Parallel Wireless: Zahid Ghadialy

Zahid Ghadialy
Senior Director, Strategic Marketing
Parallel Wireless

What industry challenges you are seeing?

The industry situation can be described as follows:

- There are legacy RAN vendors (Nokia, Ericsson, Huawei, ZTE) whose solutions are proprietary and siloed for each generation of wireless telecom (G.) Open RAN is a new movement to open up interfaces to reduce cost; driven by the O-RAN Alliance to standardize interfaces and TIP to deploy and establish an ecosystem of mobile network operators and vendors.
- Open RAN is not just separation of certain components like distributed unit (DU)/central unit (CU) — it will help with capital expenditure savings.
- There are a lot of legacy networks deployed out there with only a few true greenfield operators (even Rakuten said they were lucky they did not have any legacy). That is why Open RAN needs to address 2G/3G/4G — if only 4G and 5G are addressed, then operators will have two networks to run — legacy and new Open RAN networks — which will be costly and not serve the full purpose of the Open RAN movement
- Deploying and maintaining/optimizing networks requires a lot of manual labor and results in high cost. This can be addressed with automation/DevOps approach in Open RAN solutions

How does Parallel Wireless address these challenges?

- Parallel Wireless Open RAN is a software-based solution across ALL G (5G, 4G, 3G, 2G, and Wi-Fi); it is one unified cloud-native solution, which is horizontally distributed, not vertical silos like legacy solutions. This structure makes Open RAN easy to manage and delivers cost-savings to mobile network operators that use it to modernize legacy or expand their networks
- Parallel Wireless's distributed unit (DU)/central unit (CU) separation is for ALL G and supports all splits. As our solution includes an Open RAN controller, it enables interoperability across different hardware and cores
- Parallel Wireless's Open RAN has been deployed in 60 global networks with TIP and outside of TIP.

What is Parallel Wireless?

Parallel Wireless is the only company challenging the big legacy vendors (Huawei, Nokia, Ericsson) with the industry's first and only unified ALL G (5G/4G/3G/2G) software-enabled Open RAN solutions. Parallel Wireless's cloud-native Open RAN and network architectures redefine network economics for global mobile operators in both coverage and capacity deployments, while also paving the way to 5G.

What are the real benefits of virtualization?

When we talk about virtualization we refer to 2G, 3G, 4G, and 5G. On 2G and 3G, the legacy equipment required was very large and consumed high levels of energy. In addition, the equipment required air conditioning or other cooling equipment. With virtualization, the functions in that hardware have been migrated to software and hosted in a data center or on a commercial off-the-shelf (COTS) server. This means there are large savings in space, energy, and hardware that translate into reduced operating expenditure. There is also saving in capital expenditure as you no longer have to buy proprietary boxes but software that can be run in existing COTS servers. The investment is much lower.

What are the main benefits of Open RAN?

The main benefits are cost savings and flexibility which you cannot get now with traditional architecture. It means building a real multivendor network with no vendor lock-in.

Are you deploying your solutions for 5G or for legacy technologies only?

We are building 5G Open RAN ecosystems to help mobile network operators reduce 5G deployment costs. Our Open RAN hardware portfolio is software upgradable to 5G and can support any 3GPP-complaint RAN split. The Open RAN software suite offers a 5G native unified architecture for 2G, 3G, 4G, 5G, and Wi-Fi. The future-proof cloud-native architecture supports 5G and beyond, providing the ability to extend investments. The flexibility of the architecture allows service providers ease of migration from any previous G at their own pace and convenience.

We are suited for 5G deployments into existing networks as we help to unify ALL Gs, so instead of managing multiple G, an operator can manage 5G, 4G, 3G, 2G as one unified horizontal architecture.

The biggest advantage of unification is that it brings down both capital and operational expenses while at the same time improves the experience for the end consumer. So, the upcoming 5G technology is a chance for service providers to leverage virtualization to simplify the networks. They can then deliver 5G coverage by making deployments easy and affordable to install and maintain while sustaining a high quality of service for customers.

Software-based network architecture enables operators to utilize the benefits of advanced 5G RANs without deploying the 5G core. At the same time, 5G-like features (i.e., lower latency, e2e slicing, etc.) can be provided for all Gs. Open network architecture allows integration and interoperability with any Open RAN NR (new radio) and Massive MIMO (multiple in-multiple out), thereby reducing risk and dependency on any vendor and vendor lock-in.

Where do operators use your products, in greenfield areas or in urban areas?

When it comes to replacing technologies, operators do small parts first rather than the whole network. As we are a relatively new player, we started in rural areas as it is the most challenging market for operators and vendors to address — the user penetration is low, the average revenue per user is low, and the site and backhaul infrastructure is non-existent.

With our Open RAN solution, we were able to address the cost and deployment challenges of rural markets globally. Minimizing capital and operating expenditure is important in these low-density areas where there is high uncertainty on return. High operational cost and deployment complexity of low-density deployments have prevented operators from bringing coverage to those areas in the past.

Traditional 2G voice only and broadband 3G or 4G networks require several high-cost and often bulky equipment to deploy and operate. These types of equipment need large spaces to store, have a short life cycle, and consume energy. Besides, hardware-based networks are difficult to upgrade. By shifting networks to virtual Open RAN architectures like the technology provided by Parallel Wireless, telecom operators can overcome all these problems and deliver coverage to most remote communities at a much lower cost.

Now that we have been deployed and proven in those low-density areas for 6+ years, operators have started to deploy us in urban locations for network modernization and for 5G as our solution supports any DU/CU splits, is easy to deploy, and is cost-effective to maintain

How can Open RAN enjoy mass deployment? Is the technology ready for that?

It's not about the technology not being ready, it is more about operators needing to give the technology a chance. It is more likely to happen when operators start modernizing the networks. In that moment they are likely to try our Open RAN technology and see it works. But the technology is ready.

The problem is that everyone already has a vendor in place. All operators have to deploy 5G now and to do so they need to use the same 4G supplier because the vendors have closed the interfaces. Incumbent vendors are now saying they will open the interface for 5G but not for 4G, however, you need 4G equipment to deploy 5G so if your 4G interface is closed you will have to use the same vendor for 5G or replace everything. Right now operators cannot use our equipment for 5G on a different vendor's 4G network.

So how do you see the Open RAN taking off in reality?

Replacements will start on older sites where the technology is dated. Two major European operators are trying to leverage their power to pressure the incumbents to open the interface to have multi-vendors.

I think we will start replacing in chunks. The operators are using our equipment and the industry as a whole will show that Open RAN works, that the ecosystem works, and it will over time become a reality. We are in over 50 networks (including trials and commercial deployments).

BT just announced it has to replace a big part of its Huawei equipment — is this an opportunity for Open RAN to enter the market?

BT already has two vendors, one of them is Nokia and it shouldn't be much of a problem for them to move the Huawei equipment to Nokia now. They already have a big Nokia team so it will be easier for them to continue this way than setting up a new team to work with Open RAN.

Would you partner with other Open RAN providers?

Our vision of software-enabled architecture enables a 'white box' RAN hardware which means that baseband units, radio units, and remote radio heads can be assembled from any vendor and plugged together into an Parallel Wireless Open RAN Controller to form a truly interoperable and open network. It offers considerable cost benefits to the operators and helps them in bringing down the hardware cost. Further, it also helps in bringing down network complexity.

Operators like Vodafone and MTN have adopted this approach and have vouched for its robustness and dependability. Our Open RAN controller can manage/orchestrate other vendors' hardware. O-RAN Alliance's specifications are in line with our architecture.

Where is Open RAN being more widely considered in the world?

Everyone is now looking at Open RAN, especially since the issues with Chinese vendors arose. If you take Huawei out of the equation you effectively have only two large vendors and that is not convenient for the industry and also is very costly — you can't have a multivendor strategy. We are having our discussion globally and have deployed globally. In Africa for instance operators are looking for ways to save on costs so they are also looking at Open RAN from that perspective. In South Asia the situation is similar to Africa.

Which are the operators leading on Open RAN in Africa and Asia?

In Africa, MTN had a big announcement to do 5,000 sites with Parallel Wireless Open RAN. Vodacom is also looking at Open RAN as are other operators in the Middle East and Africa.

Everyone is talking about Open RAN but we still have legacy networks that we can't switch off. In Thailand, for instance, 2G was going to be switched off and then they realized there is a base of users on 2G/3G like credit card terminals, and they didn't switch it off. The same happened in Taiwan. This is where Open RAN can help to modernize 2G and 3G to save costs as the technology is dated.

With your solutions, do you replace everything or leave equipment from other vendors?

We can replace everything. In most cases, the operators prefer to have all equipment from Open RAN providers.

Would the cloud from a virtualized core make Open RAN easier?

No, they are completely separate. When you use cloud you have a server in a data center. Your data center can be anywhere — in the edge or centralized. But it doesn't really matter for Open RAN, you can put the software anywhere. You want the software near the core, if the core is on the edge you can put it near the edge.

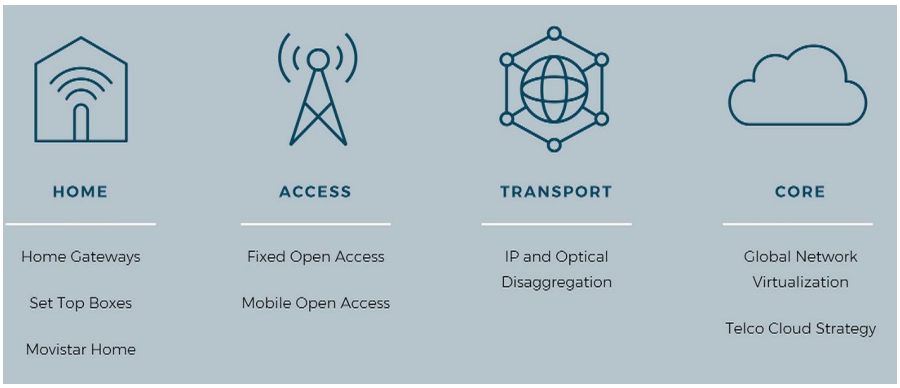
For 4G and 5G it's easier than in 3G and 4G — it depends on the architecture. Some operators prefer distributed unit, other centralized. Most mobile network operators prefer distributed RAN, rather than centralized. It is just simpler, but there are advantages and disadvantages of both these approaches.

Appendix

Networks can be divided into four key pillars: Home, Access, Core, and Transport. For this topic, the Access and Core networks are the main focus. Both parts of the network contain hardware and software. In simple terms, virtualization is the process of separating or splitting the hardware and software components of the network.

Most operators have already completed or are working on virtualizing their core networks, where there is now a decent choice of vendors. The Access (RAN) part of the network usually accounts of most of the investment (60-70%) in mobile networks. For simplicity we look at three potential network approaches for access: the traditional RAN, virtual RAN (V-RAN), and Open RAN. There are hybrid models that may come about which we also discuss.

Figure 36. Main Components of the Network: How to Drive Openness Across All Parts



Source: Telecom Infra Project 2019

Core: Functionalities of the Network

In the core network, you tend to have the functionalities of the network.

- **Traditional Vendor Model:** Each vendor has proprietary hardware and software for each of these functions. This makes it difficult to upgrade or replace, and a lot of hardware elements are necessary to deliver all the functionalities needed, especially as networks become more complex.
- **Virtualization:** Virtualization involves replacing the purpose-built hardware, and replacing commercial optical servers, allowing operators to use standardized (generic) hardware, which then allows for vendors to focus on software to deliver the functionalities. This allows for a more dynamic upgrade of the network over time and allows for more flexible product development.

Access: Opening the RAN

Focusing on the Access part of the network, the main components of the network in terms of key hardware are: antennas and the RRU (Remote Radio Unit), BBU (Baseband Unit). BBU tends to be the most expensive part of the network as it contains both hardware and software, while the RRU is only hardware. BBU is therefore the 'brain' of the Access part of the network.

- **Traditional model:** Almost all the networks deployed to date are based on this model. It has been a very successful model that has ensured reliable performance. In this model, the hardware and software are aggregated by the vendor.

The RRU (radio) is based on propriety hardware, while the baseband (which is where most of the intelligence is held) runs proprietary hardware and software. Importantly, the two are connected via proprietary interfaces. As a result, the access network is run by a single vendor. In this model, there is typically a BBU in each site to control the RRU. Each site will typically have the BBU unit in the equipment room and is connected to the RRU unit using fiber.

- **V-RAN:** The network still contains the proprietary radio equipment (RRU) of a specific vendor (proprietary hardware). But in V-RAN, you split the hardware and software component at the BBU, which can run on standard hardware, with virtualized function. The BBU can become software intensive, more scalable, and with new functionalities that can be added via software upgrades. RRU and BBU are still connected via proprietary interfaces (so still controlled by a single vendor). The advantage of this approach is that it can deliver more functionalities and could allow for the network to be run more dynamically, with some benefits in terms of agility and choice of software vendors.

- **Open RAN:** This goes a step further when compared to V-RAN to create a completely open ecosystem. In its purest/most advanced form, Open RAN separates hardware and software completely, with an open interface between them. In terms of hardware, that can allow for the use of white box solutions from different vendors for both RRU and BBU. Software vendors can be completely separate from hardware vendors and as the interface is open, any vendor software can work on the general purpose hardware. This could and over time should support multiple software vendors across all components of the network (different blocks of software from different vendors). Initially however that is likely to add too much complexity, so a single software vendor (but chosen from a wider pool) is expected in early stages of deployment.

In reality, the move from V-RAN to Open RAN can be more gradual with a number of hybrid options available in the event the vendor involved is willing to open the interfaces but still maintain the existing RRU. The network can still run proprietary vendor hardware at the RRU but with the BBU being completely virtualized (with software being provided from potentially other vendors) and the interfaces between the core computing unit and the baseband unit (CCU-BBU) are open. This is a more pragmatic approach for established operators upgrading/ replacing existing networks. The RRU could then over time be replaced by general hardware (in sync with the natural depreciation cycle).

Open RAN carries more execution risk. The traditional vendor model is a proven model, which has served the industry well over the years. The established vendors have significant scale to develop and test their solutions and run networks in every country to test their products, prior to finalizing and releasing the solutions. As most mobile operators use these solutions, the ability to differentiate at RAN level is limited, but also the risk of having a unique issue is also low.

Open RAN in principle will allow for faster deployment of technologies. By separating the hardware from the software; it allows for faster development/deployment of functionalities. As it is open to all software vendors, it increases competition and therefore innovation. But the introduction could still prove challenging. Any major changes at the network level can cause some disruption on implementation. The new software (only) vendors have yet to prove that they can deliver a superior overall solution; though the easier upgrade path means that should change over time.

Appendix 2

European Sharing Deals

Past, Present, Future

We look at the different types of agreements in Europe. There are numerous types of passive sharing arrangements in place in most countries within most operators. As investment requirements grow and returns remain under pressure, sharing is becoming more common.

Passive Can Be Common, Even Indirectly

Passive agreements are not that relevant in mobile markets with extensive independent tower companies, like for example the U.S. Indirectly, passive sharing and the efficiencies that come with that are being facilitated by the tower companies. That also helps to lower the upfront investment on any new technology or project, which also explains why small cells deployment has really taken off in the U.S. Other factors like better returns, fixed wireless broadband opportunities and the grids designed on low band also drive these investments; but sharing is a key enabler.

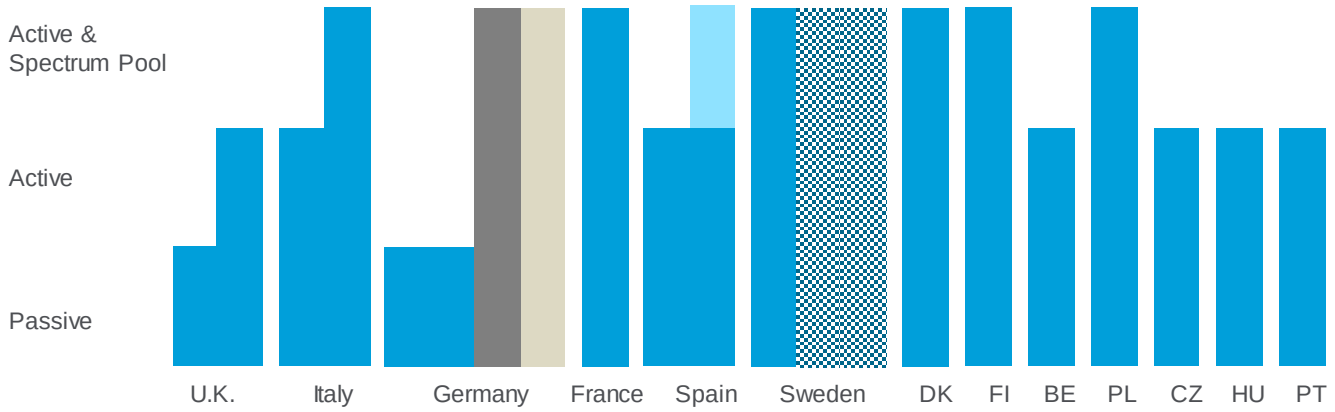
In Europe, there are a lot of regional arrangements in place, including some passive sharing and backhauling agreements that may have limited reach/benefits. We do not look into that much detail on every possible arrangement, instead we focus on the ones that drive meaningful savings.

Existing Network Sharing Agreements

Operators have been busy extending existing sharing deals as we move into 5G but also adding new ones. The deals we are seeing in recent years are of two types

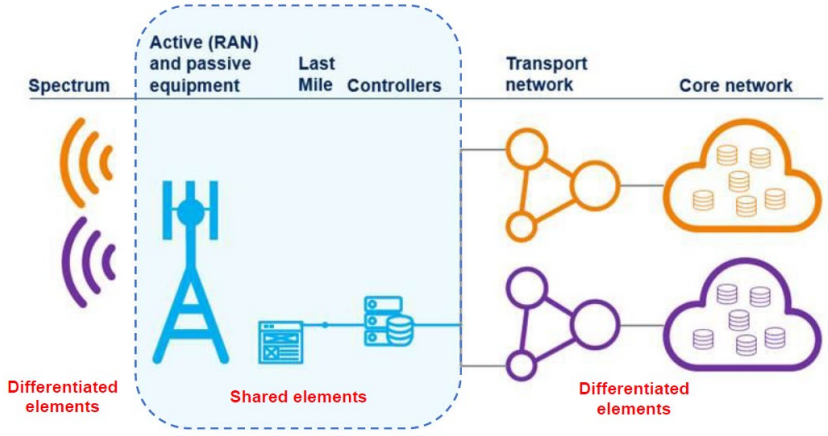
- **Active sharing deal across the existing network-** typically takes 2-3 years of investment into the network (which may even mean higher capex in some cases) but then can drive significant savings thereafter. These arrangements are either nationwide or in significant parts of the country (nationwide but excluding the biggest urban centers).
- **Active sharing to address white or grey areas:** National coverage obligations vary but in many countries coverage limits have been set in recent (and in other cases will be set in upcoming) spectrum auctions. That means that there is a need to address the so called white areas, which no network currently covers effectively. In the most demanding cases, U.K. and Germany in particularly, we have seen all the existing mobile network operators partner to reach the obligations collectively. In Germany we have also seen a more targeted agreement to also cover the grey areas, where operators 'trade' coverage in areas where currently one network is present.

Figure 37. Major Commercial Network Sharing Arrangements



* German: Grey and White area = net sharing. ** Spain: Yellow area denote options to co-invest with spectrum pooling. ***Sweden: Shaded area denotes 3G arrangements, which are now almost obsolete.
Source: Citi Research

Figure 38. Characteristics of the Shared Mobile Network



Source: Company reports

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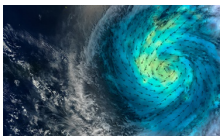

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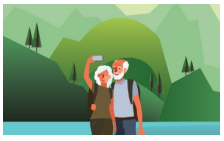

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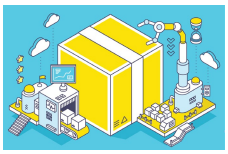

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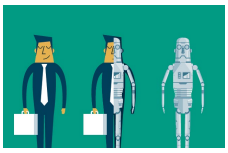

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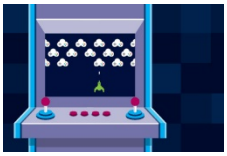

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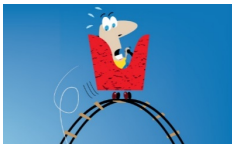

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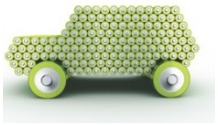

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Key Insights regarding the future of Telecom Networks

INFRASTRUCTURE

Traditional telecom networks use hardware with embedded software where both are provided by the same equipment vendor. / Similar to a smartphone, virtualization of a network separates the hardware component from the software component (apps) and replaces specialized hardware with standard general purpose hardware increasing the amount of services that can be provided.

REGULATION

Security concerns over the involvement of Chinese vendors in the deployment of upcoming 5G networks have increased over the risk of espionage. / Four countries in the Five Eyes intelligence alliance have banned Chinese vendors from official government contracts while the European Union gave new guidelines to apply restrictions for high-risk suppliers to be left out of critical and sensitive functions.

TECHNOLOGY

Traditional incumbent equipment vendors are opposed to the idea of opening up the interface between the radio and base band units. / Proponents of Open RAN are pushing vendors to open up the interface to allow competition and innovation from new software vendors, allowing operators to customize their software and differentiate their offering.