# DELL EMC AND 5G

## Analysis and strategy to capture the 5G mobile opportunity

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## Executive summary

IImagine the future – a scalable, composable and automated wireless network infrastructure that meets the high-performance needs of tomorrow's demanding consumer, Internet of Things (IoT), and mission-critical services and makes it easy to build, deploy, manage, operate, and assure new end-to-end applications. The new era of 5G networks will see not only technology innovations and operational innovations, but also business model innovations that result in intelligent devices and applications consuming and generating data like never before. These intelligent applications will introduce a new set of requirements – latency, bandwidth, capacity, coverage – that require transformation of the entire end-to-end architecture, from radio access network (RAN) to Operational Support Systems (OSS). The entirety of this software-defined infrastructure – from Cloud RAN (C-RAN) to virtualized network functions to software-programmable switches and routers, is built on common building blocks of compute, storage, and networking. What used to be possible only in science fiction movies – flying drones, driverless cars and planes, machine-to-machine interactions, seamless communication around the globe – is fast becoming a reality.

The wireless industry has always experienced accelerating demand and innovation, from the early days of cellular voice mobility of 1G to circuit-switched data of 2G to high-speed ubiquitous data access of 3G and 4G. Every decade, the mobile industry goes through a major upgrade cycle of their network architecture – from the Radio Access Network (RAN) to the Packet Core – to deliver technology innovations that meet the insatiable demand of mobile consumers and increasing proliferation and capabilities of smart mobile devices and the new generation of applications and services.

The impending 5G transition, with significant advances in bandwidth and improved latency and quality of service (QoS), will enable a new wave of services including enhanced mobile broadband, connected cars, drones, smart retail, industrial robots, and much more.

In the last several years, Service Provider networks have begun a journey towards software-defined infrastructure, leveraging the capabilities of compute, network and storage virtualization to drive new capital and operational models, deliver new services, and improve overall service delivery economics. The new operational imperatives for Communications Service Providers (CoSPs), can largely be captured in three core technology shifts:

- Leveraging increasing disaggregation of hardware and software stacks to shift workloads towards general purpose compute, such as x86.
- Decoupling core infrastructure and networking services from applications and protocols, and exposing those services as a platform to applications.
- Developing a set of information models, data models and APIs to transform operations from bespoke processes and associated infrastructure scripts, to more unified automation frameworks that allow service providers to develop DevOps-style operational processes

5G networks will be the first true end-to-end network built around these paradigms, extending virtualization into the radio access network and network edge, virtualizing the network core, and extending end-to-end network overlays for network and service slicing.

## The Dell EMC 5G strategy

Understanding these technology shifts, Dell EMC started executing on a strategy founded on the following guiding principles. Service providers should consider these suggested principles as the "new realities" to which they need to adapt in order to succeed in the 5G era:

- **5G is a new foundational architecture**, part of the continuous once-in-a-decade re-architecture of cellular networks. The changes are broader than a mere new access technology. 5G represents an important architectural pivot. Dell EMC (and, more broadly, Dell Technologies), has the opportunity not only to capture this pivot, but to lead in defining the underlying infrastructure technology.

- **5G will be the first end-to-end architecture which is fully software-defined**, from the radio through the core. Dell EMC mastered software-defined in the data center, and we are in the best position to help our service provider partners extend this all the way to edge.
- While more main stream 5G adoption is likely to be a few years away, **this is a transformation journey, not an overnight upgrade.** Dell EMC is already engaged with leading service providers, network and technology vendors, as well as industry standardization bodies, to drive the architecture evolution, 5G-related incubation, pre-production and proof of concept developments around the world.
- These **new services and applications will drive new architectural, technical, and operational models,** forcing things to be done differently from before – from design to implementation to operations.
- **The new operational model will leverage APIs and software-programmability to a level not yet seen in networking**, beyond that defined in SDN today, with the separation of control and user planes happening not just at the macro level (network), but at the micro-level (VNFs).
- **This new paradigm shift will result in an increased need for de-centralization of the infrastructure**, and cause the boundaries between "network switches", gateways, termination points and "servers" to dissipate over time . What we currently think of as the data plane of a virtual network function running on compute will move to the network switches, and what we currently think of as the network data plane will extend (virtually) into the servers. This will yield network switches which need even more "openness" and programmability than they have today, and network-integrated servers to incorporate increasingly network-orientated accelerators (FPGAs, switch fabrics, etc.).
- **The level of programmability in network switches will continue to increase beyond the current SDN-defined switch abstractions**, down to the forwarding plane itself. The network data plane is likely to become a commodity, and to leverage open source for well-defined functions. Much like the internet has its own domain-specific languages (WikiML, HTML, etc.), the network will also develop its own domain-specific language, with common higher-level scripting languages (Python, Go, Java) across the compute virtualization and network domain.
- **Operations will be driven by data, and the need to capture, process and react to network data in real-time will give rise to machine learning**. Innovation in machine learning for network data is still in its infancy. Anomaly detection – establishing a baseline of the network performance, traffic flows, and user mobility, and reacting to both gradual changes to the baseline and to anomalies – will enable predictive understanding not just of the network itself, but of macro events occurring in and around the network.
- **Openness and disaggregation of the different layers are key design principles in this new world**. While the role of open source will continue to grow, "openness" is a wider concept. Proven commercial software and tools will continue to have an important role to play.
- With all the foundational changes to the network architecture and operations, **it is fundamental that service providers also transform their partnership and procurement models** to adapt to and benefit from the openness and disaggregation paradigm.

While much of 5G is yet to be defined or designed, the rapid roll-out of the internet has shown that, in order to be successful, infrastructure needs to be flexible to cater with future use-cases, many of which cannot even be guessed at today.

## Introduction

While much of 5G has yet to be implemented, the rapid roll-out of the internet has shown that, in order to be successful, infrastructure needs to be flexible to cater with future use-cases, many of which cannot even be guessed at today.

In parallel, the shift from fixed to wireless access with the growth of the smart-phone has taken place, fueled by the movement from mobile networks being predominantly voice to exclusively data. At times, the pace of change demanded by the internet generation has been difficult to reconcile against the need to roll-out new infrastructure at national-scale. The old telco-focused models of design and deployment are no longer able to deliver the flexibility required at the speed of change demanded by new internet applications.

This paper seeks to give some historical background to the development of mobile services, explaining the move from 1G to 5G and discuss the known future demands for 5G, the changes happening in the telecom market, the changes in the landscape of equipment suppliers, as well as the development of new technologies relevant for 5G. The paper concludes with a discussion on how the open, flexible approach from Dell EMC can deliver on the broad sets of 5G demands.

## 1. 5G new demands

The ITU requirements have taken nearly 4 years to reach the point where they could be published as base-5G requirements. This testifies to the level of discussion in the industry trying to qualify the need for a new network and quantify the magnitude of the technical challenges which 5G seeks to address. As such, the ITU specification is really only useful in a type-specification for vendors. To understand why these metrics have been arrived at, it is necessary to examine the use-case behind them.

Standardization work towards the 5G radio aspects is due for completion in 3GPP Release 15, which will be "frozen" in September 2018. Important decisions towards this goal were made in March 2017. 3GPP released discussion papers on a new 5G Core in January 2017 and moved to a formal System Architecture in June 2017 with the latest versions of 23.501 and 23.502. Work is expected to take at least two years to complete the 5G Core standards.

### 1.1 New traffic types

Mobile networks were initially built with one use-case in mind: voice. In fact, the architecture, operation and optimization of mobile networks from first-generation analog to 3G mirrored that of the development of the PSTN (public switched telephone network)-based networks. The introduction of data services in 2.5G and later 3G challenged the manner in which packet-based data is carried over circuit-switched networks. RF links suffer from fading, multi-path effects and retransmissions which, in turn, cause the predominant internet protocol, TCP/IP, to behave poorly.

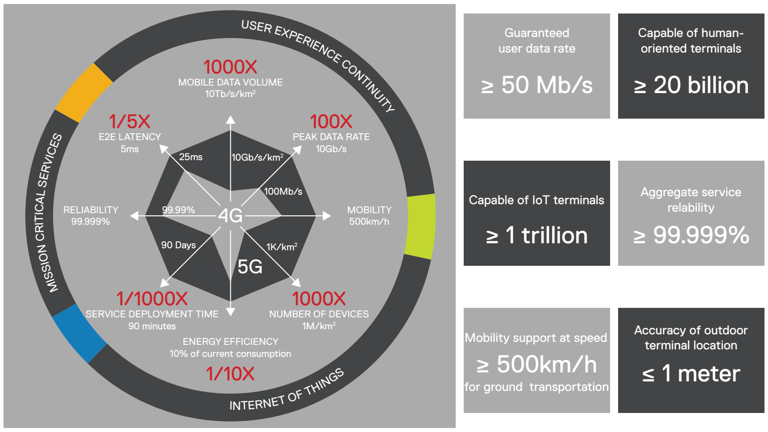


Figure 1: New Service Characteristics & Capabilities Enabled By 5G

4G, as the first all-IP network driven by data services and optimized for long-lived high-bandwidth streaming video, has provided some relief, but there remains a disconnect between the operation of the air-interface and packet throughput performance. Consequently, even though "headline" data rates on LTE appear to be close to wired connections, actual throughput can seem to be significantly lower, accompanied by high-levels of latency.

In LTE, voice-traffic is simply another data service. Significant complexity had to be introduced to ensure that voice-quality can be maintained under all conditions, including segregating data-traffic associated with the voice service on specific air-interface modulation types, partitioning the network traffic into low-latency forwarding schemes, enacting methods for monitoring radio performance and taking evasive action should RF quality drop below given thresholds, and also deploying dedicated core networks that were optimized for voice traffic models.

For these reasons, along with the initial lack of LTE ubiquity, voice over LTE (VoLTE) did not appear immediately. Instead, operators opted to deploy 4G networks for data and continue to leverage existing 2G/3G networks for the delivery of voice service. This has prolonged the life of both 2G and 3G networks, and led to the early appearance of IoT services on these increasingly under-utilized networks.

## 1.2 IoT

Presenting perhaps the widest set of uses cases (and the most challenging for any network infrastructure to carry efficiently), IoT presents challenges in the amount of data, the immediacy of the data and the sheer number of devices, with estimates ranging from 6 to 50 billion devices by 2020 (Source: IEEE Spectrum, 2017).

Due to the range of potential applications and services, it is not possible to arrive at a single definition of IoT. Instead, it is imperative to look at some diverse IoT use-cases and their impact on the network to understand just how disparate the requirements might be:

**Use Case 1- Factory Automation:** Manufacturing plants are getting smarter. Machines will host hundreds of sensors and actuators giving visibility and control not only to local staff but to remote operators. This is often the case in large manufacturing plants where the machines will be owned/operated by the original equipment manufacturer (OEM) but located in the customer premise. The issue here becomes both the sheer number of devices and the control-loop latency: the presence of the OEM in the control-loop in current mobile architecture would add many milliseconds of delay to the machines' control functions. 5G networks, in this instance, are expected to have the ability to connect, collect and process device functionality close to the edge, but under control of a distant service owner, the OEM. The key to success here is including the OEM in a manner by which the local functionality is unaware of the extra connections, yielding the creation of what is known as the IoT Gateway.

Key technologies in 5G include:

- The ability to connect to devices over non-standard RF interfaces and the ability to position software/application functions close to the edge using local compute functions, such as those specified in ETSI Multi-Access Edge Computing (MEC).
- Networks will also need to be sliced (logically separated) to ensure sufficient isolation and security between public and private application instances. For the operator, the key is to be able to deploy functionality locally to the end devices from a single management instance. Network slicing is inherently built on the principles of SDN.

**Use Case 2 - Sensor Networking:** Often seen as the bedrock of IoT development, sensors are being embedded in everything and "cloud-based" solutions are being offered to consume and present this data. Mostly, the data produced by these sensors is small, not overly time or delay sensitive, and sent at regular times but with a long period. This presents a number of issues in today's networks which must be addressed in 5G:

- Sheer number. RF capacity is a finite resource. Techniques to re-use and share spectrum plus identify new areas of spectrum are required.

- Geographical spread. While sensor networks can be anywhere, the main available spectrum is in the short-range >6GHz bands. Deploying new base-stations is expensive and increasingly difficult to do. 5G imagines an "ultra-densification" of RF connectivity, but this may prove to be impossible to achieve given market economics and a lack of available sites. Therefore, flexible solutions whereby local-area coverage networks can be built to serve a particular area or group of sensors will need to be developed. Flexibility is the key here – being able to use existing or common compute assets to provide RF connectivity, transparent management operation for the SP, etc.
- Traffic Profile. Simple sensors will produce minimal levels of data – a temperature reading may only be a few bytes of data. In today's networks, transporting even a few bytes requires many more bytes of overhead, adding to the overall cost of transport. In an internet predominantly concerned with carrying large amounts of high-value data, those overheads could be justified, but with IoT, this is no longer the case.
- Device Power. Many IoT sensors are expected to be small, long-lived (20+ years) battery-powered devices located in remote, inaccessible areas or deployed only once. Current mobile technology is built predominantly around the smart-device which measures its battery life in hours. While some of this is due to the intensive processing on the device itself, a large proportion is due to the nature of serving the RF interface. Technologies such as LoRA and services such as SIGFOX have concentrated on optimizing battery life through the use of for-purpose RF techniques which do not integrate to current mobility systems. 5G will seek to provide connectivity to suit this market.
- Identity, Security and Management. Aligned to the above issues, one-time deploy devices where power needs to be managed are designed in such a way that their identity is expressed in a simplified manner compared to the protocol-intensive methods used in today's mobile systems. The primary method of providing identity and security in cellular systems is via the SIM card; these will often cost more than the entire IoT sensor. Likewise, software patches can be applied to a smart-device with sufficient power and compute functionality over-the-air; this is unlikely to be the case with IoT sensors. These differences impact both the sensor and the network supporting it: software on the device at build time should really be seen as existing for the life of the device, and therefore for many years. The network will need to be aware of these complexities as well, as changes which would potentially disconnect thousands of IoT sensors (for example, due to a protocol change) are going to prove troublesome to manage.

## 1.3 AR/VR

VR/AR has the potential to swamp the current networks with its demand both for raw bandwidth and very stringent latency requirements (Qualcomm, 2017). Ultra-high quality immersive video already requires bandwidth in the order of several hundred Mbit/s, although, depending on the application, it can be quite delay-tolerant. However, video, when applied to remote control and tactile IoT applications such as remote diagnosis, tele-medicine or hazardous environment operations, makes demands of both bandwidth (in the order of 1 Gbit/s per video stream) and latency. King's College London's Tactile Lab paper (Aijaz et al. 2017) shows the effect of adding latency to the control loop of a haptic actuator and associated robotic arm, demonstrating that the entire control loop, both in terms of RF delay and application processing overhead, needs to be less than 10ms and closer to 1ms in such applications. This is beyond the 50+ ms minimum latencies seen on today's mobile networks.

More problematic for the headset/immersive VR applications is Virtual Reality Sickness: the effect on the wearer of poor quality video coupled with excessive latency (over about 10ms).

Given the physical limitations of the air-interface and spectrum availability, it is obvious that some of these issues can only be solved by positioning as-much of the content and control close to the user.

Key technologies which will enable VR/AR in 5G include:

- Local placement of services via the use of pre-positioned content to reduce latency. MEC is an ideal candidate solution.
- Orchestration of services across different access media. The ability to manage the provision of software from 3rd parties (e.g. gaming software, remote diagnosis, etc.) into the edge-compute system.
- High-bandwidth services. VR/AR solutions call for high definition and ultra-high definition video. Densification of the RF layer will be required. Technologies such as C-RAN whereby area-wide baseband processing will be necessary to meet this need.

## 1.4 Mission-critical

As mobile coverage becomes ubiquitous and the "connection method of choice" services, currently delivered on for-purpose networks which have been engineered to provide some form of tolerance to failure and/or availability, will migrate to the mobile network. While some of these services will simply have service levels in excess of a consumer-grade service, others will be engaged carrying safety-critical traffic, for example vehicle-to-vehicle, rail transport, fire/flood alerting systems, etc.

This requires that the network have the ability to deliver against defined service levels. Redundant systems may also be required on the network with data shared/stored in such a manner that it retains availability without compromising security. There is no means today to declare that a particular data service is critical and requires specific handling through the infrastructure. 5G will provide methods by which data context can be determined. Additionally, in times of emergency, networks may become partitioned. 5G will have the ability, through local compute functions, to place elements close to the affected area, ensuring that critical processing continues.
Key technologies within 5G which enable the handling of mission critical communications are:

- Control/User Plane Separation: the ability to steer traffic which carries criticality into a network slice which has been engineered to provide a different level of availability and/or redundancy than other parts will enable SLAs to be defined.
- C-RAN: densification of the access network in areas where mission-critical data is connected requires rapid fan-out of RF connectivity.
- Edge Services: in order to provide redundancy in the event of network loss, some mission-critical applications will need to be relocatable to the edge of the network. For example, in the case of a weather-related event, local cellular service should be able to survive in the event of a failure in a central core network. MEC will enable such functionality.

## 1.5 Enhanced mobile broadband

While the current data services available on LTE networks are "one-size-fits-all", it is not uncommon for the actual throughput to vary across a large range, especially while moving at speed. Additionally, all data travels over the single packet core and discriminating traffic into discrete user-groups is complex. While local break-out services such as Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) are available, these are rarely used, as defining which connection a particular session should use is difficult.

Economically, it is difficult for operators to provide comprehensive data services in low-usage and unusual locations. It is not uncommon for urban areas to have a choice of four or more operators with good data rates, while rural areas have one or even no available operator. Given such variability in coverage, it may be difficult for the consumer to choose the optimal operator. Other environments, such as planes or trains, are notoriously difficult to provide coverage to in a multi-operator environment.

The goal of 5G is to provide ubiquitous connectivity at high data rates in all locations, whether moving or at rest. 5G will also allow user-group access for specific data – for example, the enterprise email service on a user's handset will always be routed over a specific connection for that traffic and not over a default "internet" connection. This means that specific traffic handling (SLAs, security, etc.) can be applied to different traffic across the network.

As the demand for high-speed mobile data access increases across a range of transport systems, new multi-operator connectivity will be required to enable passenger access to data services without each operator needing to deploy their own specific equipment. Likewise, rural areas could be served in a manner which provides connectivity via a single set of infrastructure where it is uneconomical for each operator to deploy their own. New business models and companies will emerge to fulfil this "Neutral Host" market; these companies will be built on a new range of open, lower cost networking solutions.

Key technologies which will enable the widespread roll-out of eMBB at moving speeds of up to 500km/h are:

- Cloud Radio Access Network (C-RAN): Neutral host operators will be able to deploy dense connectivity in specific locations and scale the centralized processing using flexible physical or virtual Base Band Units (BBU). Existing operators will use C-RAN to provide wide-scale roll-out of new 5G connectivity.
- Multi-Edge Computing (MEC): Pre-positioning content close to the edge, especially in mobile environments such as trains and planes, will be needed to keep the backhaul costs down. Likewise, rural areas where high-bandwidth connectivity may be expensive or prohibitive in terms of transit time (long circuits to very remote areas) will require MEC functionality.
- Control and User Plane Separation of EPC nodes (CUPS): being able to separate traffic into different categories and treat according to SLA and/or ownership will enable defined classes of service.

## 1.6 Data plane performance

Virtualization and "softwarization" are key foundational elements in the construction of a new 5G core network. The benefits they can bring in terms of flexibility and time-to-market are clear.

In addition, the new demands on the 5G Core will require data rates in excess of nx10Gbit/s across the network with minimal latency in some instances (see previous discussion). The goal of 5G is to decrease transit times and latency. All current virtualization solutions add latency to the throughput. The ability to off-load traffic through the 5G software core components to ensure expedience of forwarding will therefore be important, and a number of new data optimization techniques are being developed.

Along with the well-known Data Plane Development Kit (DPDK) from Intel, other stack bypass solutions exist whereby traffic can avoid having to transit portions of the virtualization system. However, many of these optimization techniques are hard-tied to a particular virtual instance, be it a container or hyper-visor solution, and therefore impact the very flexibility which "softwarization" seeks to address.

Key technologies in 5G which will seek to address the impact on packet forwarding are:

- FPGA: Hardware-based field-programmable gate arrays (FPGAs) can be used under control of the core elements to bypass and "switch" data in an optimal manner.
- SDN: the ability to program an entire network function chain such that optimal forwarding based on a traffic class and/or SLA is key to 5G.
- Control/User Plane Separation: Some traffic may not be concerned at high latencies (e.g. email), whereas others will be negatively affected (VR/AR). Multiple user-plans based on the traffic profile will exist in 5G with different technologies as appropriate for the traffic type.

As well, the stateless nature of 5G operations between the control plane and user plane contributes to achieving the specified 5G latency targets.

## 1.7 Network efficiencies

### 1.7.1 Spectrum

Since the wide-scale installation of fiber backbones in the 2000s, while last-mile capacity has been problematic in some geographies, the wired internet predominantly has infrastructure capable of delivering near-term traffic needs.

The same is not true in the raw commodity needed for mobile system – RF spectrum. This highly valuable asset is tightly controlled and allocated and suffers from a dichotomy: the longer-reaching lower frequency spectrum is the one that provides the least bandwidth capacity, whereas the higher-frequencies can provide the required bandwidth but do not have the required range.

Governments around the world are also keen to reclaim legacy spectrum and have already indicated that they expect 5G to be the vehicle by which some for-purpose legacy systems can be repurposed. These governments have been busy building out digital transmission systems for radio and television to replace analogue, usually not just to improve the range of services on offer, but also to gain from better spectral efficiencies in new modulation techniques. Switch-over to Digital Terrestrial Television is nearly complete in most EU countries, saving substantial amounts of spectrum in the 800MHz band (a very useful band for future cellular solutions). Switch-over from broadcast AM and FM to digital systems has not progressed at the same rate, but take-up is increasing due to the rapidly falling cost of receivers; both Germany and the UK are now at over 50% of radio listening on digital systems and both are considering switching-over.

### 1.7.2 Seamless mobility

5G will also need to tackle these challenges of how to make the service appear to be continuous while the connectivity underneath changes. A good example, which not only highlights the potential to consolidate spectrum more efficiently but also explains the challenges faced by 5G designers, is the UK government's decision to replace the current standalone TETRA-based cellular system. This system is similar to 2.5G networks with an Emergency Service network on a future 5G solution as a VPN on one (or more) of the current MNOs. Key features required for emergency services include capabilities not in the 4G specification, such as pre-emption (the ability to seize resources from other users), talk-groups both within a user-community and the ability to set-up new communities quickly, the role of a dispatcher and ultra-low call setup for Push-to-Talk (LTE has a Push-to-Talk over Cellular, but the call setup is not fast enough for emergency services usage).

However, unlike current 4G LTE, the current UK-wide TETRA network provides 100% geographical coverage. Providing national coverage instantly at switch-on has never happened with new mobile roll-outs, so new techniques, such as the ability to interoperate with existing infrastructure, will be required.

Additionally, the very notion of "national" coverage will challenge the concept of the competitive MNO – most operators will cover quite similar areas with similar revenue-potential equally well as they cannot afford to deploy to loss-making areas. Roaming between national operators, while technically possible, is not the norm, is not seamless (an LTE re-attach is required which will cause all sessions to drop) and is a drain on battery resources (mobile devices in their "home" area currently do not search for alternate networks in order to preserve power).

Both of these examples, however, beg a similar question: in terms of national infrastructure spend, would it have been more efficient to have a single infrastructure solution, such as 5G, able to provide the variety of services?

The truth is that the technologies of the time when the infrastructure decisions were being made – mostly 2G or 3G – were not flexible enough to be able to deliver anything other than their primary purpose services. There is a lesson here for 5G: the solution needs to be flexible enough to be able to handle services which we haven't even considered yet.

## 1.8 Operational efficiencies

In the telecoms industry, across the space of about 30 years, we have seen several waves of technological change, but in many cases, the new technology has not fully replaced the original. For example, in 2017, a number of 2G networks still existed around the world in a fully operational and fully supported state.

Why is this? Firstly, the time involved in deploying national infrastructure is extended – most countries do not have full 4G coverage as of mid-2018 despite roll-outs having started many years previously. Additionally, coverage ratios and penetration rates within many emerging economies for 4G have yet to reach values that generate financial returns similar to those of developed markets.

Secondly, the funding cycles rely on new investment being driven by revenue derived from the existing or new services. In some aspects, there is a chicken-and-egg issue here – the argument may be made that if an entire network were to be put in place from day one, new revenue would flow. However, experience of 3G shows that this is not always the case: the vast sums paid for spectrum in 3G have not yet been matched in new revenue. Also, macro-economic circumstances may slow the investment pay-back making the original network unprofitable. To some extent, 4G has suffered from a difficult macro-economic situation.

Thirdly, existing users cannot be disenfranchised simply because a newer technology exists. Migrations between technologies need to be planned. This is especially the case with 2G, which has found some niche uses in M2M. We find 2G equipment placed in remote and difficult-to-access locations such as ATMs and vending machines.

Finally, cutting across from one technology to the other requires that the new technology provides services at least as good, in terms of coverage and quality of service, as the ones it is replacing. Such technology transitions therefore happen over extended time-periods. An example of this is the move in the UK from 405-line TV to 625-line TV. This move started in 1967 but was not completed until 1985, with the two systems running side-by-side. A similar move to digital terrestrial television was planned to take only 5 years, starting in 1998, but due to the dot-com bubble of 2001, the eventual switch-over was not completed until 2012 (Given, J. 2003).
Given current short funding, investment cycles and the uncertainty of the new revenue sources, 5G will need to offer more than simply a new, parallel set of infrastructure. At least in the early days, most of the revenue derived from 5G will

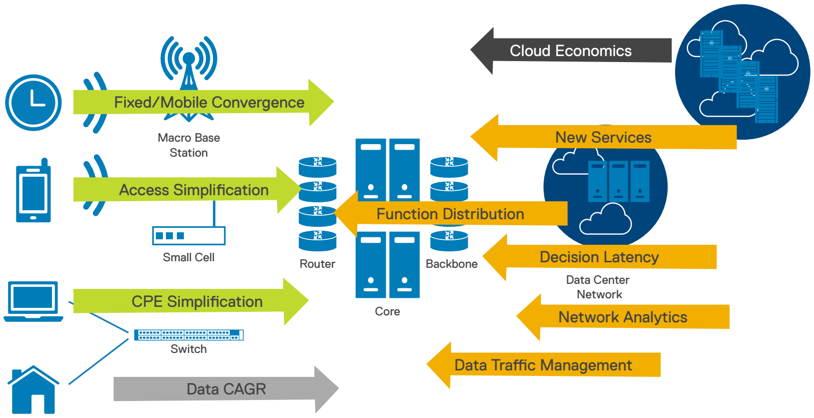


Figure 2: Shifts in the Mobile Architecture(s) and Value Chain

come from savings in the operational state of existing technologies and in the ability to rapidly deploy new elements as use-cases are identified.

Therefore, 5G is more than a new solution; it is about re-working existing solutions in a manner whereby cost-savings can be made. For example, moving today's 4G packet core to a flexible platform which can be expanded to provide additional services and/or capacity is seen as a 5G facet – the current EPC solutions are difficult to expand and are built as a one-size-fits-all solution. Likewise, the ability to deploy new processing and/or storage solutions around the network is not currently possible. 5G will look to make this possible.

The inflexible architectural constraints of for-purpose hardware and software solutions inherent in 2G, 3G and 4G have not allowed optimum efficiency in the current deployments. 5G will not only introduce new technologies in packet-core, access and RF, but will enable some of the existing solutions to be re-worked into more dynamic, flexible deployments.

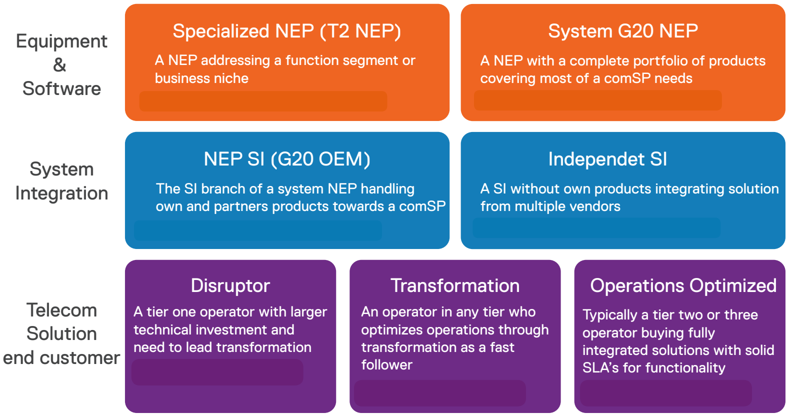
At the same time, presenting both new and existing elements as a single management domain will help reduce costs due to the proliferation of OSS/BSS systems which has occurred as each new technology has brought with it its own management and operational model(s). 5G will look to address orchestration within both new and existing technologies with the goal of reducing operational cost and complexity. Many studies into Management and Orchestration (MANO) are ongoing, such as the ETSI OSM group (OSM, 2017) or the Open Network Automation Platform (ONAP) initiatives.

## 2. Telecom industry status

In previous "Gs" time, the telecommunications industry could be seen as a specific business defined by the special requirements around "carrier-grade" (99.999%) operation and a large number of regulatory requirements. This industry was also bounded by the relatively few service providers and the even fewer providers of complex system solutions and components. This resulted in a situation where Network Equipment providers (NEPs) (Originally Nortel, Ericsson, Lucent, Alcatel and Siemens. Now, Huawei, Ericsson, Nokia, Alcatel Lucent, and Cisco) and operators created relationships in which the NEPs where extensions of the technology departments of the operators. This relationship was also amplified by operations outsourcing agreements and other contractual stipulations. In many instances, the existence of the operator and the NEP were intertwined.

The relationship was such that the NEPs drove standards and development via 3GPP, and then built equipment in a greenfield market that was not questioned by the operators. At the time, it was more important to provide a working service and then build a market share at a premium in competition with other national operators. In an economic environment of rising customer average revenue per user (ARPU), this relationship was in balance. The solutions built were bespoke and proprietary, with the exception of the 3GPP interfaces that enabled interoperability of the functional nodes in the network. At the same time the 5-9's requirements drove a verification, validation and acceptance methodology associated with a very high assurance, but at the cost of long lead times in deploying or upgrading network functions.

The technology development and innovation in cellular communications has been deliberate: iterative to ensure no major disruptions to carrier-class operations, and timed to ensure that operators recoup some level of CAPEX outlay through service revenue. When compared with "internet speed" deployment and availability of new services and features, deployment within the mobile industry has been slow. Consequently, consumers have moved to other providers for their services and applications, diminishing the role of the cellular operator largely to transport and connectivity. This move of revenue has challenged the ability of the operators to invest and likewise has had an impact on the NEPs.



Equipment & Software

**Specialized NEP (T2 NEP)**
A NEP addressing a function segment or business niche

**System G20 NEP**
A NEP with a complete portfolio of products covering most of a comSP needs

System Integration

**NEP SI (G20 OEM)**
The SI branch of a system NEP handling own and partners products towards a comSP

**Independet SI**
A SI without own products integrating solution from multiple vendors

Telecom Solution end customer

**Disruptor**
A tier one operator with larger technical investment and need to lead transformation

**Transformation**
An operator in any tier who optimizes operations through transformation as a fast follower

**Operations Optimized**
Typically a tier two or three operator buying fully integrated solutions with solid SLA's for functionality

Figure 3: Shifting Roles Across the Mobile Supply Chain

As early as 2012, operators, realizing that a radical change and modernization were required, generated proposals around Virtualized Network Functions (VNFs) to open-up the telecom infrastructure. Citing the dominance of a handful of NEPs as well as high costs, they suggested a separation of the execution environment from virtualized network functions running on top. This change required the cooperation of NEPs to provide such infrastructure-agnostic network functions, but as this was not in the best interests of the NEPs, and consequently, the development to this end has been slow. The result is that we now see virtualized verticals replacing the legacy integrated stacks with little actual gain in the operational efficiency the operators so badly require.

Longer term, we will reach the full potential of NFV. There are specialized NEPs prepared to produce the disaggregated network functions and challenge the incumbents. In this scenario, there is a need for a new actor who will build the disaggregated telco data center; this can be either one of the big NEPs or one of the emerging system SI companies (e.g. TMH, Atos). The disaggregated telco data center is a key component for Dell EMC in 5G. Investments in new infrastructure and software creates the momentum needed for a change of sourcing, development, system-integration and deployment principles to enable the disaggregation. The disaggregation also turns infrastructure from components in a telecom vertical into a full underlay independent infrastructure system requiring less telecom expertise.

Traditionally, infrastructure was sold to operators for telecom network functions as an OEM through the NEPs. The model has changed slightly and some equipment is now sourced directly, but on strict specification, from the providers of the network function software. The main reason for this lock-in is due to the verification and certification processes mentioned previously. Every network function in every version is verified and certified on a specific set of infrastructure components. This process has contributed to the slow roll-out of new services.

Telecom procurement will evolve such that verification and certification will be based on scalability, orchestration and reporting. With such paradigm, the question would no longer be how much can run on this hardware but rather what resources are needed for a function with a specific (workload) profile. Thus, specification and procurement of infrastructure for a telecom environment would be much more like IT procurement, building agnostic data centers as resource pools.

Abstraction of the infrastructure to enable certification of the solution, for example, in a similar manner to VMware whereby certification of the software is automatic on specific infrastructure where the VMware installation is itself certified, enables rapid deployment on “known good” installations

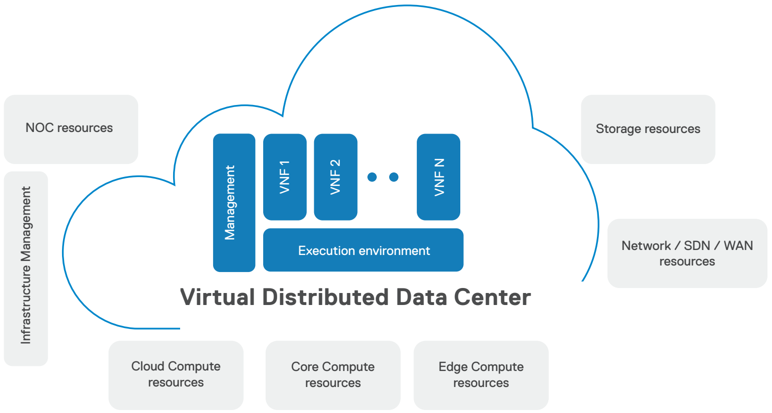


Figure 4: The Emergence of a New Mobile Cloud Blueprint

based on reference architectures rather than the current first-principles approach.

The telecom data center will therefore evolve from a centrally located, for-purpose system into one encompassing compute in different physical locations with a single orchestration plane, thus creating one homogenous execution environment in which to place workloads.

Dell EMC's Ready-X (figure X) 4G. 5G, edge computing and other validated solutions accelerate roll-outs and minimize product, technology, integration and vendor risk (for VMware and OpenStack environments). These validated solutions bring together the best of IT and mobility capabilities and provide open, disaggregated solutions with best of breed VNF and service enablement capabilities from a broad ecosystem of vendors.

## 3. Technology advances

Unlike previous mobile roll-outs, 5G is not a wholescale replacement of existing technology with something new. It is a way of evolving what already exists and of re-imagining the architecture so that maximum flexibility and operational efficiency may be made from current and future infrastructure.

As in previous generation lifts – but even more so for 5G – we see a significant out-of-domain technology enabling the core technology, particularly in virtualization and automation/orchestration. We also see major changes in how networks are developed and deployed that come from the agile methodologies in the broader software industry as well as use of micro services as a way to reach speed and flexibility.

The technology advances can be grouped into five major areas – the big 5 – comprising SDN, NFV, MEC, Air I/F and Automation. The latter area is rather wide and collects technologies for reduction of OPEX and TTM as well as flexible service creation.

### 3.1 Air interface

Probably the biggest difference between 5G and previous generations is the lack of a new air interface. Instead of mandating a new air interface as 2G, 3G and 4G have done, 5G uses the existing LTE air interface in existing spectrum but augments its capabilities by overlaying a new air interface above 6GHz (Qualcomm, 2017a). In fact, this air interface is based on the same technology as that used in LTE, OFDM, but with several changes:

- 5G NR uses CP-OFDM, which has narrower shoulders than LTE usage of OFDM meaning that better use can be made of the spectrum (less requirement for guard-bands).
- Single-Carrier versions of 5GNR exist (SC-OFDM and SC-FDMA) which are more suited to devices with limited battery life such as used in IoT in mMTC.

- MIMO techniques are enhanced and aggregation can be accomplished across spectrum jumps allowing for massively enhanced data throughputs such as are appropriate for eMBB applications.
- Collaborative services will be able to be operated not only across spectrum used for 5GNR but also with LTE Advanced, meaning that the 5G capabilities are additive to current services.
- Spectrum can be split between mMTC, eMBB and Mission-Critical as needed, including in unlicensed space.

The use of higher frequencies will require a denser rollout of base stations; operators will need to be able to deploy systems rapidly and cheaply. New techniques in SDR will mean that many cell sites will consist in "dumb" Remote Radio Head (RRH)-type of deployments with the baseband processing backhauled to compute functionality located regionally and/or centrally. C-RAN type deployments may also no longer be linked to a single operator, as is the case with existing range extension such as DAS. So-called "neutral host" solutions, able to provide multiple operator access, will appear, alleviating the difficulties associated with the in-building deployment of small cells for LTE.

## 3.2 Packet core: General

Today's 4G LTE Packet Core is built around the same design principles as that of the original 2.5G networks. That architecture was based on the voice central-office design with switching centers to provide transit service between endpoints and to/from the rest of the network. While the end-station is mobile, the architecture is static, using a serious of network tunnels to create the illusion of mobility. This architecture has proved to be acceptable for delivering voice and text services, but is limited in its ability to provide the high bandwidths and low latency required for interactive video and the ultra-low latency required for IoT applications.

3GPP has published a new 5G Network Architecture in 23.501 (3gpp, 2017). However, while this describes new interfaces and opens the way to potential network re-design, 3GPP does not envisage a whole-scale change in the operation of the packet core within the first deployments of 5G services. We can therefore expect to see the existing protocol stack of GTP and IP remain based on anchor-points for some time. In the interim, two modifications to the current architecture will start to introduce 5G concepts to both the 4G LTE and 5GNR air interfaces in order to address the performance requirements of the new use-cases: virtualization (and by association, network slicing) and edge functionality.

### 3.2.1 Packet core: Virtualization

A key technology which will be necessary to enable the flexibility and scalability required in the 5G-capable packet core is virtualization.

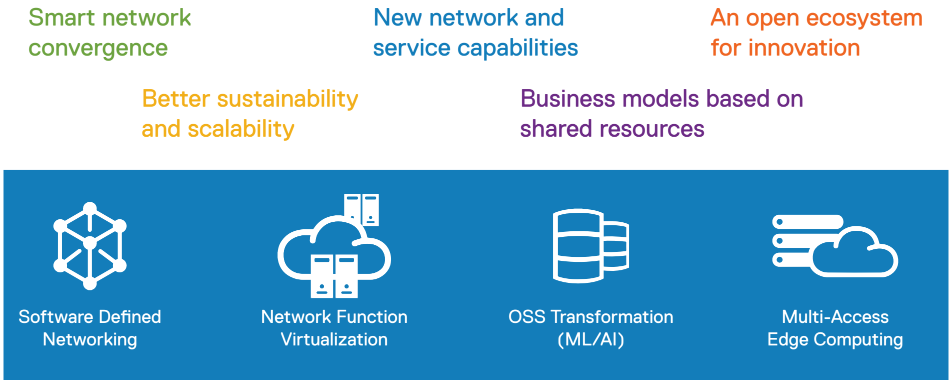


Figure 5: Technology Transformation Domains

First, the current 4G packet core components are re-named and re-architected in 5G and will evolve as the 5G protocols are refined. Operators will need to be able to deploy these technologies rapidly, and the monolithic, for-purpose packet core components as deployed in 4G and before will not be appropriate. Orchestration and automation of deployment will also mean that the 5G core will be able to react to traffic utilization by scaling up/down components. As new use-cases emerge, the 5G core will be able to support these traffic types, as operators will not have to install new equipment as was the case for 2, 3 and 4G.

Second, solving the latency issue for critical applications will require placement of services close to the user. Having a virtualized environment able to host applications and software of use to the end-user will be key in 5G.

Third, 5G will be able to run network slices: independent instances of the core network for specific purposes (e.g. a closed-user group, specific traffic types or security requirements). Operators will be able to build a sliced network able to split by user and/or traffic type, such that the best experience is given to each use-case rather than a one-size-fits-all as is the case today.

The ability to provide flexible virtualization features located at all levels of the network but with a single operational view, coupled with automation features which understand traffic flows, network constraints, etc. and take autonomous action to maintain service against defined SLAs, is key to delivering a virtualized 5G core network.

### 3.2.2 Packet core and edge services

Just as with the wired internet where the proliferation of CDNs close to the subscribers has improved video delivery, the wireless internet requires that services are placed close to the user where optimal data experience is required. Delays of over 50ms are not uncommon on today's 4G LTE EPC; this is unacceptably high for the control loop timings of IoT applications or some video such as AR/VR.

Multi-access Edge Computing (Dahmen-Lhuissier, S., 2017) considers how content and applications may be moved to the edge of the network, often at the cell site or pre-aggregation site in a mobile network, in order to provide lower latencies than would be possible where services are centrally located. MEC instances can also be placed into network slices whereby a user community accessing the same content source or application can be re-directed to use a local version located on compute close to the edge. Likewise, elements of the packet-core, currently a fixed architecture, can also be relocated or co-located on edge compute functions removing latency from the session.

The key to a successful MEC solution is that the orchestration and operation should be transparent to not only the end user who need make no change to their application, but also to the operator; the network orchestration will build and deploy appropriate services to edge devices. MEC may be deployed on existing 4G LTE networks as well as being a core component of 5G.

Common to both virtualization and slicing of the packet core and the ability to deploy edge services is the need for a universal compute solution available at every point on the network where appropriate functionality may be deployed. The benefit of such a platform is that new, hitherto undefined applications may also be hosted on this platform. Experience of the rapid growth of the internet has shown us that trying to second-guess what applications and services will appear in the future is futile. The ability to adapt to whatever the market demands is key.

An example of a possible future hosted application is the move towards centralized (or partially centralized) baseband processing for RF known as C-RAN. With the developments in RRH technology, baseband processing is becoming less of a cell-site feature and more a compute function. As 5G will see a proliferation of cell sites, baseband processing could become a very important distributed compute requirement.

## 3.3 SDN

SDN is key for many other advances. For example, for orchestration to be efficient, the network configuration must be under automation or API control as well. In the same way, with a software defined transport layer with richer function sets than what has been available in the past, it is possible to move low touch network functions into the transport network. The creation of distributed virtual cloud environments requires transparent networking between locations or for the private network structure to be set up per application or tenant in the network, which would not be possible under the existing manual paradigms.

Advances in switch and router hardware as well as development of SDN controllers has accelerated in the past years and is expected to accelerate further in the years to come.

One consequence of bringing SDN into mainstream telecom is that the organizational setup of the industry will change. Separate network departments will have to go from running the network operations into running the equipment and handling interfaces and policies.

A technology of special interest in the SDN area is that of domain-specific languages to set up service chains with processing in the switching infrastructure or in of-load accelerators placed in banks. With the switching infrastructure fast approaching a switching fabric with function placement all the way from the L2 switch through accelerators and on to a smart NIC including a virtual switch component in the processing domain.

## 3.4 Automation, orchestration, reporting and analytics

This area is perhaps the most complex, due both to its broad nature as well as to the multitude of technologies needed to make it work. Generally speaking, this is the area where agile service creation is enabled and, with that, where much of the value in the 5G network will be created.

Virtualization in various forms including hypervisors and containers has already been brought into the telecom domain with NFV, and in turn requires software to manage the new resource types. Cloud management platforms such as OpenStack and VMware fan out from managing virtual resources to also manage workloads and services.

Going the other way, there is technology emerging for bare metal management, BMaaS, and new initiatives in infrastructure management, like RedFish in the rack-scale infrastructure sphere, making for higher utilization and more flexibility.

For automation to work, there is a need for policy-based decision systems and information gathering for the decision models. Current advances in streaming analytics and big data fits well into the area of network analytics in 5G that will enable the whole chain, from reporting on the state of the network to automatic problem detection to solving further to predictive analysis of the networks. These functions are today deployed in other industries and fit well into the requirement picture for 5G.

Another area from the IT industry that will be fundamental for 5G is catalogue-based service creation both for application and service management using flexible template-driven approaches such as TOSCA.

Finally, automated security analysis and enforcement is becoming far more important with the increased flexibility and openness of the 5G networks. These technologies are being used elsewhere in enterprise IT but have not been seen as needed for the closed and static operations of telecom.

The way applications are built in other industries with micro services and agile deployment will drive the use of software frameworks such as Cloud Foundry, even though they are not yet ready to take on the full scope of telecom software. This will also lead to some parts of the telecom software stack being deployed as a service from the cloud, utilizing technology similar to Amazon AWS and Salesforce.

## 4. Dell EMC's perspective on 5G

It is increasingly obvious that the cellular telecommunications industry is at a point where the future 5G network will require levels of flexibility not currently possible with monolithic solutions. Orchestration across multiple domains and the ability to consolidate and re-architect today's services to react quickly to changing network conditions and for network capabilities to adapt to service requirements, while enabling rapid deployment of new functionality is the panacea that will enable operators to seek out new revenue streams.

New actors from the non-traditional Telco space continue to appear and expect to be able to deploy their services into the 5G environment in the same manner in which they deploy into the cloud. New customer relationships will be formed where neither the traditional NEP nor the MNO holds the contract with the end-user. This will require more openness in terms of access to the infrastructure than has been the case up to now. Operators will no longer have the ability to run long-term test and validation cycles, given the increased set of services and the myriad of combinations of solution. Instead, operators will expect the infrastructure components to be tested as a set of reference solutions and architectures and with the ability for the components to monitor and correct for deviation from those references.

OSS/BSS must be simplified, work across multiple component providers and have a degree of autonomy not currently found. Additionally, it must understand and react not just on infrastructure KPIs but on end-user experiences and SLAs.

As the industry moves to software-defined infrastructure in both RAN and network core, sensible placement of functionality between software and hardware components based on cost per component rather than software vs hardware for pure ideological reasons will prevail. In some instances, it will be more efficient to use components such as FPGAs for data processing – for example, in high-speed packet forwarding, encryption off-load and C-RAN processing – but in others, a software-based solution may be more advantageous. The key is open access to each of the components and orchestration across them such that the infrastructure makes the choice based on overall efficiency, not by the component chosen by a specific manufacturer.

In short, tomorrow's 5G infrastructure requirements, with an emphasis on multi-actor, distributed, work-flow-based deployment in an efficient and agile manner, look a lot like today's large-scale IT cloud solutions. Dell Technologies is therefore uniquely positioned to provide solutions at CoSP-scale.

While elements of the 3GPP 5G solution are still under discussion, the 5G Systems Architecture 23.501 is defined and it is possible to map the major components to Dell infrastructure.
It is also interesting to note that a distributed bus-based approach to the common core functions has been taken with 5G – this again is in common with distributed processing and message-bus techniques prevalent in Enterprise IT environments. Each of these has an interface defined by the prefix "N" (e.g. Nnnsf, Nausf) described as a "services-based interface" more akin to a data model than a traditional protocol.

Each of these elements exists per-slice, under control of the orchestration. Therefore, there has to be a compute environment provided capable of spinning up/down each of the functional elements as required. Mapping each of these components to their resource requirement can ensure stricter SLA enforcement. An initial judgement can also be taken on the requirements for these components and summarized in Table 1. Compute intensive functions, especially in RAN and UPF, lend themselves very well to hardware off-load techniques such as SmartNIC and/or FPGA, and developments are already being seen in these areas.

Orchestration and Service Assurance techniques found in Enterprise IT will also become more important, as management of multiple networks is currently challenging

|  | Compute Intensive | Database System | Message Bus | Data Forwarding | Latency Critical |
|---|---|---|---|---|---|
| **NSSF** |  | ✓ | ✓ |  |  |
| **NEF** |  |  | ✓ |  |  |
| **NRF** |  |  | ✓ |  |  |
| **PCF** |  |  | ✓ |  |  |
| **UDM** | ✓ | ✓ | ✓ |  |  |
| **AF** |  |  |  |  |  |
| **AUSF** | ✓ | ✓ | ✓ |  |  |
| **SMF** | ✓ | ✓ | ✓ |  | ✓ |
| **AMF** |  | ✓ | ✓ |  |  |
| **UPF** | ✓ |  |  | ✓ | ✓ |
| **(R)AN** | ✓ |  |  | ✓ | ✓ |

Figure 6: Mobile Blueprint and the Dell EMC Opportunity

for operators with items in their own domain. Managing multiple instances across domains and locations will be even more onerous unless work-flow methods are used to control elements.

The increased network and service agility will require tools such as real-time analytics as well as orchestration tools provided by the VMware portfolio.

## 5. Conclusion: Dell EMC - Powering The Cloud-Generation Mobility Era

While as an infrastructure technology vendor, Dell EMC's role in defining the functions and services that make up 5G may be limited (3GPP standards, baseband radio technologies etc.), Dell EMC has a significant role in driving the evolution and advancement of the various workload execution environments.

Beyond 4th Generation (4G) mobility, the Dell EMC product portfolio helps bring the best of IT, service and workload management and mobility capabilities together over one unified, validated platform. With its "Ready-X" 4G, MEC, IoT and 5G solutions, Dell EMC accelerates a new generation of mobile rollouts while minimizing product, technology, integration and vendor risk over a variety of cloud management platforms, with the added benefit of a curated ecosystem of VNF and services partners.

Beyond the infrastructure foundational elements (NFVI), and where appropriate, Dell EMC also leverages the broader Dell Technologies portfolio (VMware, etc.) to automate and accelerate mobile operations, enable premium user experiences with optimized economics. These unique workload profile management, visibility and security capabilities increase operational agility and optimize operating costs across geographies, administrative domains and organizations.

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## B. Abbreviations

| | |
|---|---|
| 3GPP | Third Generation Partnership |
| AMPS | Advanced Mobile Phone System |
| AR | Augmented Reality |
| ARPU | Average Revenue Per User |
| BBU | Baseband Unit |
| CDMA | Code Division Multiple Access |
| CP-OFDM | Cyclic Prefix Orthogonal Frequency Division Multiplexing |
| COTS | Common Off The Shelf |
| C-RAN | Cloud Radio Access Network |
| DAS | Distributed Antenna System |
| eMBB | Enhanced Mobile Broadband |
| EPC | Evolved Packet Core |
| ETSI | European Telecommunications Standards Institute |
| EVDO | Evolution Data Optimized |
| FPGA | Field-Programmable Gate Array |
| GPRS | General Packet Radio Service |
| GPU | Graphics Processing Unit |
| GSM | Global System for Mobile Communications |
| IM | Instant Messaging |
| 3GPP | Third Generation Partnership |
| AMPS | Advanced Mobile Phone System |
| AR | Augmented Reality |

| | |
|---|---|
| ARPU | Average Revenue Per User |
| BBU | Baseband Unit |
| CDMA | Code Division Multiple Access |
| CP-OFDM | Cyclic Prefix Orthogonal Frequency Division Multiplexing |
| COTS | Common Off The Shelf |
| C-RAN | Cloud Radio Access Network |
| DAS | Distributed Antenna System |
| eMBB | Enhanced Mobile Broadband |
| EPC | Evolved Packet Core |
| ETSI | European Telecommunications Standards Institute |
| EVDO | Evolution Data Optimized |
| FPGA | Field-Programmable Gate Array |
| GPRS | General Packet Radio Service |
| GPU | Graphics Processing Unit |
| GSM | Global System for Mobile Communications |
| IM | Instant Messaging |
| IoT | Internet of Things |
| ITU | International Telecommunications Union |
| LI | Lawful Intercept |
| LTE | Long Term Evolution |
| M2M | Machine to Machine |
| MANO | Management and Orchestration |
| MEC | Multi-Access Edge |
| mMTC | Massive Machine Type Communication |
| MNO | Mobile Network Operator |
| NEP | Network Equipment Provider |
| NMT | Nordic Mobile Telephone |
| OEM | Original Equipment Manufacturer |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OTT | Over the Top |
| PSTN | Public Switched Telephone Network |
| RAN | Radio Access Network |
| RF | Radio Frequency |
| RRH | Remote Radio Head |
| SC-FDMA | Single Carrier Frequency Division Multiple Access |
| SC-OFDM | Single Carrier Orthogonal Frequency Division Multiplexing |
| SDR | Software Defined Radio |
| SLA | Service Level Agreement |
| SMS | Short Message Service |

| | |
|---|---|
| TACS | Total Access Communications System |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| TD-SCDMA | Time Division Synchronous Code Division Multiple Access |
| TETRA | Terrestrial Trunked Radio |
| UMTS | Universal Mobile Telecommunications Service |
| URLLC | Ultra Reliable Low Latency Communications |
| VoLTE | Voice over LTE |
| VPN | Virtual Private Network |
| VR | Virtual Reality |
| W-CDA | Wideband Code Division Multiple Access |

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