A 5G AMERICAS WHITE PAPER

THE PROGRAMMABLE 5G NETWORK AND API ECOSYSTEM

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5G americas

Contents

Executive summary

The cellular telecom industry is at the cusp of a major shift driven by several factors, both opportunistic and contextual. In the large technology context, virtualization of the network infrastructure is opening the door to a more dynamic and agile approach towards network functions as they get implemented in software. The software and IT industry in the meantime are going through their own transformation with the push towards the cloud, containerization of payloads, and functional decomposition of monolithic applications into modular services. It was just a matter of time before the two worlds converged to create a huge, combined opportunity for the telecom industry to adopt new service delivery and business models.

Conceptually, programmable networking has been around for some time, but it is only now that benefits of programmability can be materialized by Communication Service Providers (CSPs) through a Service-Oriented Architecture that enables “as a Service” (aaS) capabilities. And just as for IT as a Service, as a Service in the cellular realm relies on the ability to hide network service implementation and complexity behind a programmatic “contract” in the form of Application Programming Interface (API). To enable APIs as a “menu” into network services it is imperative for operators to provide application developers a “franchise-like” framework where irrespective of the establishment, developers can count on the same set of capabilities that conform to a uniform set of standards, specifications, and processes. Adhering to the principle of **Triple S** (**Secure**, **Simple and Scalable**), network services and their corresponding network APIs must be **secure** and preserve user’s privacy, **simple** to use by application developers not familiar with networking protocols, and be able to **scale** to fit the requirements of users and operators across multiple geographical domains and markets. Initiatives such as GSMA Open Gateway[1], Linux Foundation CAMARA project[2], and TM Forum Open Digital Architecture (ODA)[3] are working together to establish the network API Franchise of tomorrow.

According to a recent McKinsey report[4], this technology transition can produce between $100-$300 billion industry-wide revenue over the next 5 to 7 years. To unlock this huge opportunity and generate returns on the sizable investments made in the network infrastructure, the industry needs to grow an ecosystem involving developers, enterprises, hyper-scalers, vertical industry players and vendors while engaging in new market structures such as aggregation and federation.

For North American stakeholders, a cohesive roadmap on standards-based APIs driven by market needs is necessary to stimulate demand while addressing specific privacy and consent requirements. The API ecosystem calls for Mobile Network Operators to act as partners and remove any friction points for the consumers of these digital services while preserving key characteristics of reliability and security associated with existing connectivity services.

1. Introduction: Scope

There's been a lot of coverage in the media and analyst reports on the topic of programmable networks, network APIs and other emerging technologies enabling CSPs to open their platforms for new business opportunities.

This paper aims to provide the reader with a condensed summary of the technology landscape and market opportunities while providing a cohesive view into the realm of network programmability and its complex, multifaceted emerging ecosystem.

After delving into the technical and business context that is paving the way including key drivers, enablers and the potential use cases, the paper goes into deeper detail on network APIs, their role in the larger scope of programable networks, industry initiatives that are facilitating standardization and commercialization of these APIs, as well as key stakeholders in this modern telecom ecosystem, their roles and interdependencies. The paper concludes with an evaluation of business opportunities while acknowledging and discussing challenges as well as call for action.

For the sake of clarity here we use several terms that are being referenced throughout the paper:

Communications Service Providers (CSP), according to Gartner[5], offer telecommunications services or some combination of information and media services, content, entertainment and application services over networks, leveraging the network infrastructure as a rich, functional platform. CSPs include the following categories: telecommunications carrier including Mobile Network Operators (MNOs), content and application service provider (CASP), cable service provider, satellite broadcasting operator, and cloud communications service provider.

Network as a Service (NaaS), according to IDC[6], is "an emerging procurement model to consume network infrastructure via a flexible operating expense (OpEx) subscription inclusive of hardware, software, management tools, licenses, and lifecycle services." It usually involves whole or partial components of the network, for example management infrastructure only or overall management and routing infrastructures, to be hosted on the cloud and offered on a "pay as you go" or similar subscription models. Software Defined Wide Area Networking (SDWAN) offers are examples of NaaS.

Communication Platform as a Service (CPaaS) defined by Gartner[7] is a platform that "offers application leaders a cloud-based, multilayered middleware on which they can develop, run and distribute communications software. The platform offers APIs and integrated development environments that simplify the integration of communications capabilities (for example, voice, messaging and video) into applications, services or business processes."

Connectivity as a Service (CaaS) is an evolving term as CSPs build their services towards the needs of the Enterprise. Through CaaS customers are allowed to define and manage their connectivity through their own portals. CSPs have an opportunity to turn CaaS into a powerful tool for targeting enterprises. However, as outlined in a recent TMForum report[8], CSPs need to focus on the customer, prioritize projects, learn from NaaS initiatives, automate partnerships, adopt open APIs, cloud native architectures and focus on security. They will have to collaborate with many partners to make it happen, from working together to adopt the necessary standards and best practices to enable CaaS, to partnering in digital ecosystems in order to deliver the capabilities enterprises want.

2. Programmable networks

Programmable networks can mean many things depending on the context of discussion. Other terms such as open networks, virtualized networks, network as a service (NaaS), communication platform as a service (CPaaS), are also used in same contexts as programmable networks but they mean very different things. To be clear let's start with some basic definitions.

Programmability, meaning ability of a system to change its behavior based on instructions, has been used in various technology sectors, including telecom, and is usually considered a highly desirable attribute. A programmable system is a more flexible, and even thought of as being more intelligent system, implying ease of change, ease of addition of new capabilities, and ultimately ease of expansion of overall system value propositions. Programmable systems allow instructions to be applied to them through clearly defined interfaces, aka Application Programming Interfaces (APIs), that can be accessed through well-defined sets of rules. Programmable networks allow access to a set of resources through APIs. The exact set of resources and methods of access depend on the network and context of usage.

Open systems are characterized by standardized interfaces which allow interaction with external entities. Open networks are usually defined as networks where controllers can be interchanged from one vendor to another with ease due to highly standardized interfaces that are used in building such controllers. Most modern networks are open systems based on a set of well-known and established standards, e.g. 3GPP, IEEE, IETF, ITU.

Virtualized systems are defined as systems where software and hardware are decoupled so as to allow use of commodity hardware to run specialized software loads. Virtualized systems tend to be more flexible and faster to change due to complexity of the system residing in software as opposed to specialized hardware. Virtualization is a key concept in cloud computing through which generic cloud-based infrastructure can be used to execute specialized software loads. Virtualization applied to networking is also referred to as Software Defined Networking (SDN). Modern virtualized networks are much more dynamic, easy to change, and capable of serving at various scale. For cellular networks benefits of virtualization and disaggregation are introduced through 5G enhancements starting with a fully virtualized packet core that has been disaggregated into functional components (Network Function Virtualization). Similar disaggregation and virtualization will continue through evolution of Radio Access Network (RAN).

2.1 Key drivers

Digitization trends in all aspects of life and business have been driving increased demand for connectivity and automation which can only be achieved with modernization of legacy systems. In the context of cellular networks, programmability is one of the steps towards such modernization. Key drivers for improvements in programmability of the cellular networks include:

Technical drivers:

- Shift to Software as reflected in 5G enhancements specifically virtualization of the packet core into functional components that can be deployed in a distributed architecture enabling interfaces to external functions to create new services.
- A similar shift to software in the RAN space is also promising to enable further flexibility in network design, particularly in the last mile access networks.
- Advances in compute platforms, providing greater scale and speed for processing of data at various locations of the network, core or edge. Flexible workloads can be placed in various points of the network enabling customization of network behavior, as well as integration with external applications that can enhance service creation and delivery.

Business drivers:

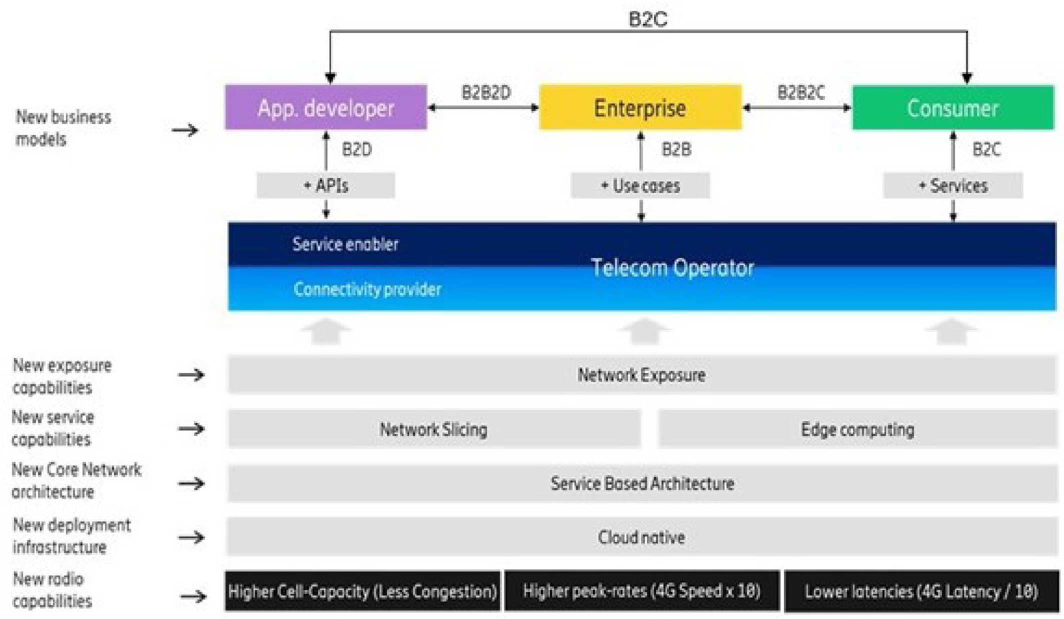
- Commoditization of Connectivity and through it a push towards higher level and more complex service categories. Many of the new services, offers such as CaaS, or CPaaS, are only possible through closer integration of telecom networks with Application Service Providers. This trend continues as service descriptions evolve through addition of new technology such as Artificial Intelligence (AI).
- Increased demand for IoT and Automation in complex enterprises whose footprints span large, and increasingly multiple disparate, geographical areas. The new emerging use cases may have connectivity requirements that can exhaust existing enterprise networks, based on WiFi, therefore pushing enterprises to consider other advanced connectivity solutions.

2.2 Use cases

Use cases that can be enabled through increased and improved programmability of cellular networks are varied and still evolving. Needless to say, opening up of interfaces and increasing flexibility of integration of various legacy components can lead to innovations that were not possible before. In that spirit there are many industry-wide initiatives and discussions underway to define new and innovative use cases that can leverage cellular operators' immense collateral and capabilities.

The following diagram attempts to draw out major business and technical layers that are being defined, and refined, and which can drive new use cases for a modern, flexible, and powerful cellular network.

Figure 1. Enhancements in cellular networks that can enable new use cases



Examples of emerging use cases include remote patient monitoring in the healthcare industry, fraud prevention through Know Your Customer (KYC) features across many verticals, SIM Swap in various verticals like financial services, advanced supply chain visibility in retail, predictive manufacturing, smart factories, smart grid, and smart cities. In all cases network's capabilities include IMS (IP Multi-Media Subsystem) voice, Video and Messaging services, basic connectivity services as needed in IoT, location services, dedicated spectrum, bandwidth, and low latency through network slicing and edge computing, and real-time data analytics.

A comprehensive set of use case definitions can be found in the appendix.

2.3 Enablers

Given the complexity and breadth of cellular networks standards-based developments and industry alliances continue to be essential for facilitating adoption of new technical and business advancements at global scale. Cellular networks, as a large subsection of the broader "networking" technology segment, have participated in evolution of networking technologies and been influenced and benefited from various new features and capabilities that have emerged in modern IP based networks. In the area of programmability, however, cellular networks have not kept pace with the broader internet. This delay is mostly due to the complexities of cellular network architecture and operation, as well as business models that ultimately intend to deliver positive outcomes for the stakeholders of these networks.

Advent of 5G heralded a transformative era in cellular telecommunication industry, introducing a service focused architecture that promises to revolutionize network interactions with the digital world. There are three large categories of transformation that are being initiated by 5G and that continue to evolve: Packet Core related, RAN related and UE related. These enhancements are enabling new ways of interactions both within cellular networks as well as between cellular networks and entities outside the cellular network like application layers and/or other networks.

2.3.1 Packet Core enhancements initiated through 3GPP

Through the 5G set of enhancements, the highly static and large components of the cellular network, such as the packet core, which have historically resided in large and complex appliances, are redefined as open virtualized software-based systems that can run on commodity hardware platforms either centrally or in a distributed architecture, either locally or on the cloud. Network Function Virtualization of the packet core allows replacing hardware-based network functions with software-based ones in order to better optimize the network while increasing efficiency, flexibility, and capacity of the infrastructure. Disassociation of various functions of the packet core, i.e. data plane, control plane, and management planes, enables positioning of these functions at different scale in different locations of the network depending on actual usage profiles and traffic loads which can change and easily readjusted. Positioning of critical functions at various network “edge” locations, closer to user workloads, can reduce latency and improve overall quality of experience enabling support for latency sensitive workloads. Virtualization is only one of the many enhancements being introduced into cellular network architecture through 5G. The ultimate goal of 5G enhancements has been to enable cellular networks to support increasingly varied and more sophisticated workloads than previously possible enabling a shift from the traditional CSP offering of voice, SMS and Data to new service models. With 5G enhancements CSPs are now able to slice and dice cellular network capabilities into consumable services to be used by developers to serve various enterprise ecosystems.

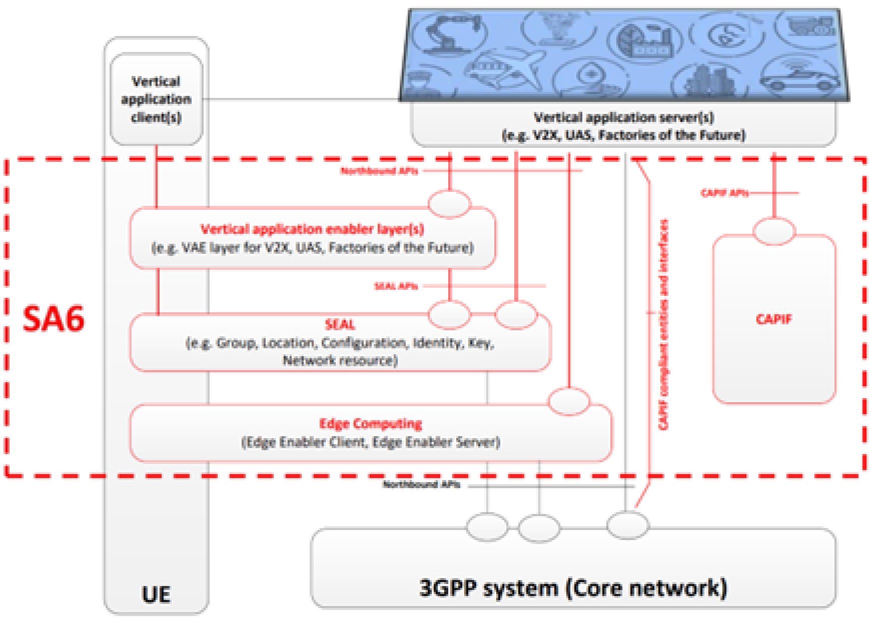
APIs play a critical role for enabling 5G enhancements. The 5G Service-Based Architecture (SBA)[9], utilizes a modular approach to interconnect network functions (NFs) through the Service-Based Interface (SBI), a well-defined REST interface based on HTTP/2. The architecture includes dedicated network functions, namely Network Repository Function (NRF) and Network Exposure Function (NEF), to enable internal and external access to the core network services and capabilities. Internally, NRF facilitate coordination among other NFs by providing directory services and discovery of function capabilities. Externally, NEF empowers CSP to expose the 5G network service and capabilities to third-party applications through northbound APIs. As a whole these modular groupings provide connectivity, quality of service (QoS), policy enforcement, subscriber data management services, as well as act as a gateway for third-party applications to securely interface network services and capabilities. Furthermore, the Network Data Analytics Function (NWDAF) facilitates the data collection from 5G core network functions for analytics and AI, where the interactions between endpoints are managed through SBI or NEF northbound APIs.

To align with modern API definitions, 3GPP has adopted OpenAPI[10] specifications for the use of YAML[11] as a human-friendly data serialization language. Also, recognizing complexity of API access in cellular networks where resources can be controlled in multiple administrative domains, each controlled by a distinct CSP, and where application developers needing to access these resources have to be authenticated and authorized by the resource controller(s), 3GPP has established the Common API Framework (CAPIF)[12] for 3GPP Northbound APIs, which supports authentication of API invokers and authorization of their access to services. CAPIF can also manage the registration and exposure of APIs, ensuring that third-party entities can discover and utilize them efficiently. Therefore, CAPIF is instrumental in upholding the integrity and security of the 5G network’s API ecosystem, making it an essential feature for the realization of 5G openness.

The Service Enabler Architecture Layer (SEAL), introduced in Release 16 by SA6, is another cornerstone of the 5G service framework, specifically tailored for vertical applications. It provides a suite of application plane and signaling plane services that are reusable across various vertical domains. These services, including **group management, configuration management, location management, identity/key management, and network resource management**, are specified as CAPIF-compliant northbound APIs for individual services, enabling flexible integration with vertical applications. As the 5G ecosystem continues to evolve, SEAL is expected to support more common capabilities based on the requirements of new verticals.

On top of SEAL, 3GPP SA6 defines **Vertical Application Enabler** (VAE) layer, which refers to a specialized component or set of capabilities designed to support specific industry verticals within the 5G system. These enablers play a crucial role in enhancing communication for vertical markets such automotive, drones, and factories of the future. The standardized VAEs bridge the gap between the 5G system and specialized applications, enabling seamless integration of 5G services for diverse industry sectors.

Figure 2. 3GPP SA6 Initiatives to enable new vertical applications[13]



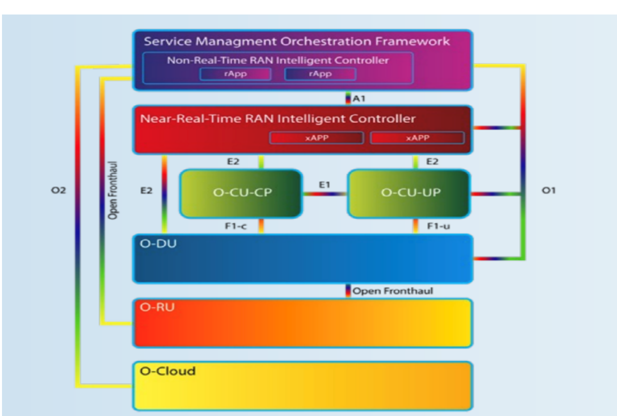
With the integration of CAPIF and SEAL, along with the comprehensive application enablement standards provided by 3GPP, 5G is set to offer an unprecedented level of control and flexibility to service providers and application developers alike, paving the way for a smarter, more connected world.

2.3.2 RAN enhancements going forward

In addition to packet core enhancements, 5G has also introduced a large set of enhancements to the radio. Many of these enhancements involve an update to the radio technology that optimize spectrum use, introduce additional spectrum bands, optimize radio power profiles, and overall provide a more efficient radio system. In parallel to the 5G enhancements, the RAN technology sector has also been going through evolutionary changes to modernize the RAN stack. These changes include disaggregation of the RAN stack and transition of various RAN functions into software. Details of these enhancements are well covered in 5G Americas papers, including Open Ran Update, November 2023.

The O-RAN alliance[14] is a central group worldwide where RAN modernization is being standardized.

Figure 3. O-RAN Architecture[15]



When it comes to RAN programmability O-RAN-Alliance has set the path to leverage use of AI/ML in Radio Access Network by introducing RAN Intelligent Controller. Developing area includes AI/ML applications in the NG-RAN and the Air Interface, focusing on use cases such as energy saving, load balancing, mobility optimization, and enhancements in Channel State Information (CSI) feedback, beam management, and positioning accuracy.

RAN Intelligent controllers (RIC), either near-real-time or non-real time, can help improve the performance management and optimization of the radio Network. The real time and non-real time RIC address different operational time scales leveraging xApps to optimize RAN performance dynamically and rApps for strategic network management and optimization. E2 interface connecting the near-real-time RIC to RAN nodes and the A1 interface facilitating communication between the non-real-time and near-real-time RICs are standardized interfaces to ensure ease of interoperability to leverage different xApps and rApps vendors to integrate their solution components into O-RAN solution.

AI-RAN Alliance[16] leverages O-RAN Architecture to introduce AI/ML programmability into RAN networks. With a goal to attain Sustainable Network for AI Era, focuses on Network Transformation, Business Transformation and Sustainability. Multiple approaches include realizing and harnessing potential of AI native RAN, Enhance RAN capability and performance, RAN Asset Utilization and usher AI based innovation to propel profitability with mission goals including:

- **AI on RAN**: AI based applications such as computer vision etc run on RAN infrastructure, essentially engineering the resources to host these applications on common infrastructure. This is basically deploying AI services at the network edge through RAN to increase operational efficiency and offer new services to end customers/mobile users. e.g. 5G Connected Camera Workload Application Processing hosted on RAN infrastructure. Essentially an MEC use case, where MEC and UPF and RAN is on same infrastructure
- **AI-and-RAN**: This is essentially RAN Infra sharing free Capacity for AI Application. Envisioning use of free resources from a VRAN instance for AI workloads, with cloud sending tasks to clusters when compute resources are available
- **AI For RAN**: AI Increasing RAN efficiency (RIC use case). Envisioning AI for RAN performance enhancement/optimization, better QoS/QoE. Several AI applications aim at solving unique constraints, to achieve better spectral efficiency, ensure KPI/SLAs are met for application specific requirements

2.3.3 User End point (Device) enhancements

The end point connecting to the network is a critical junction of activity as it bridges the network to the end user, be it a human or a machine, as well as can be a critical point of application invocation, either as a point of application execution or as an edge to the cloud. There are several topics surrounding device enhancements in order to meet demands of a modern and highly programmable cellular network. These include: zero touch provisioning, continuous monitoring, and secure network attachment, edge compute capabilities, and many more. There are also new devices, and/or device groups, that are being developed to enable a richer user experience, examples including modules that can fit inside robots/AGVs/drones, Telematic Control Units fitting inside vehicles, wearables such as headsets for new emerging applications involving AR/VR, etc. Most of these developments are cutting edge and at early proof of concept stages, therefore standardization of many aspects of end user devices remains a work in progress.

Nevertheless, in this rapidly evolving landscape, device-based agents and eSIM technology are at the forefront of innovation, offering a new paradigm for connectivity and network management. Device-based agents, often embedded within the device’s firmware, act as intermediaries between the device and network services, enabling dynamic interactions and enhanced control over network functionality. The eSIM, or embedded SIM, revolutionizes traditional SIM card approaches by providing a programmable and secure identity module that can be remotely provisioned and managed, allowing for seamless network switching and updates without physical SIM swaps.

The integration of eSIM technology with device-based agents facilitates massive IoT deployments, which is essential for meeting the increasing connectivity demands of IoT. This synergy is particularly beneficial for IoT service providers and connectivity providers who are grappling with the challenges of managing vast fleets of devices. The GSMA eSIM standards[17] SGP.31 and SGP.32, designed for massive IoT, are instrumental in this regard, offering a framework for efficient subscription management and remote connectivity. Network APIs play a crucial role in this ecosystem, serving as the conduit through which device-based agents communicate with network services and manage eSIM profiles. Device-based agents and eSIM technology, in conjunction with network APIs, offers unprecedented flexibility, efficiency, and control, essential for the next generation of mobile and IoT devices.

3. Cellular Network APIs

Networks, being one of the most complex systems ever built using computers, continue to depend on APIs for multiple purposes. Historically, conversion of User Interfaces to Application Programming Interfaces has been enabling automation of configuration activities that have primarily happened manually through a human operator. Operators have been able to automate many steps in their network management activities, including interactions with OSS/BSS systems, using network APIs. With SDN, use of APIs in network design increased beyond the basic automation of CLI and OSS/BSS interactions. Disaggregation and virtualization of network components would not be possible without robust APIs that can abstract away complexities of various components allowing developers to focus on higher levels of innovation. Modern networks, as defined in 5G for example, consist of highly modular service components, connected through rich APIs, that can be custom configured to meet specific customer demands. In these networks specific sets of APIs are used to connect and configure **internal** systems, i.e. internal to the operation domain, while a separate set of APIs can be used to allow overall system to interact with **external** applications that can extend overall system capability beyond simple connectivity. This level of flexibility for network design and interactivities with non-network applications paves the way for further automation of DevOps in various verticals.

3.1 Modern APIs

Modern data APIs are architected according to several design principles which help to modularize and separate responsibilities. Among the many core principles employed by modern APIs there is:

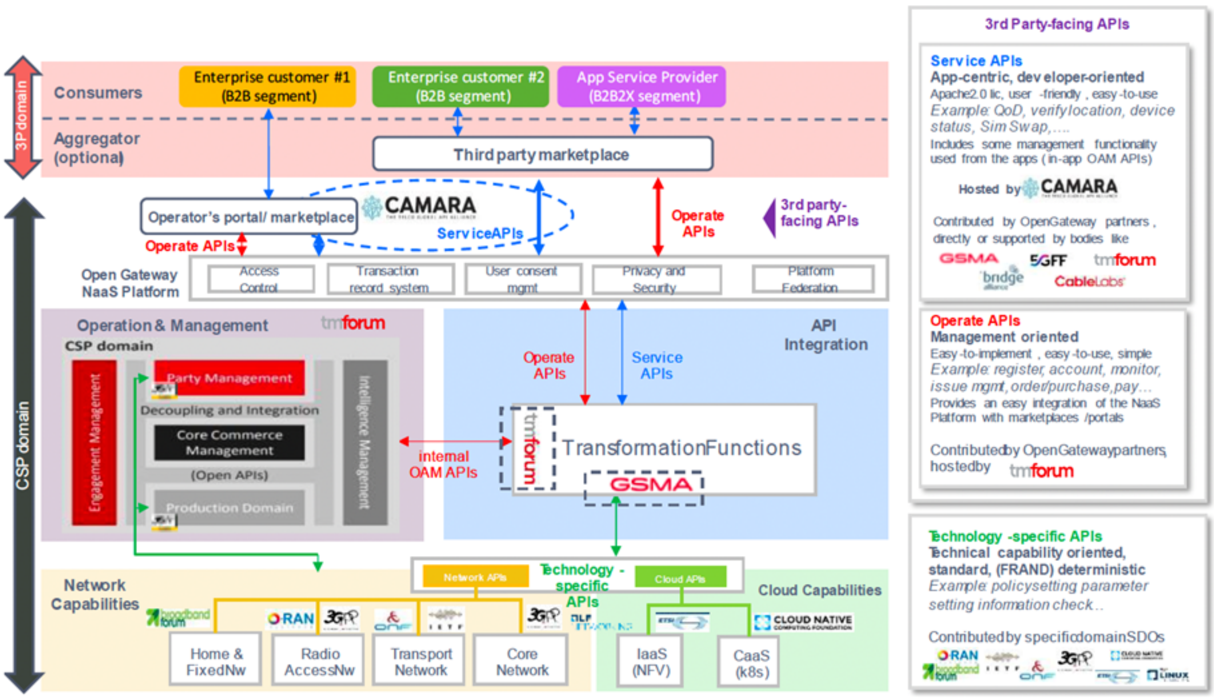
- Distributed Architecture -- A modern API platform utilizes a distributed architecture with many API gateways for greater scale and availability.
- Centralized Control -- While gateways are distributed, configuration is centrally controlled through a management plane, enabling organization-wide governance, consistency, and observability into the API ecosystem.
- Infrastructure Agnostic -- Gateways can run anywhere, such as on bare metal, VMs, containers, Cloud; providing the flexibility modern organizations need.
- Automated Configuration -- API configuration and policy should be code, enabling DevOps practices around infrastructure-as-code.
- Developer Self-Service -- Teams can self-provision gateways and services with appropriate security and other functional controls in place; facilitating speed and decentralization.
- Holistic Lifecycle Management -- The API lifecycle needs to be managed through design, development, deployment, operating, and monitoring/observability.
- Security Controls -- APIs need to fit into existing security layers or respond to policy directives such as those that fit into a Zero Trust Network Security framework.

The OpenAPI[18] Specification, formerly known as the Swagger Specification, is the leading specification that embodies modern API requirements. Its adoption by the cellular industry paves the way for evolving cellular network APIs to meet modern day application and service demands.

3.2 Telecom industry initiatives for API

Industry-wide initiatives such as standards are important in that they define the means to achieve interoperability among different vendors in the supply chain. Standards, however, do not provide a blueprint nor define performance and other differentiating characteristics. To fill the gap between standards and actual service delivery, several industry initiatives have emerged, most prominent being CAMARA[19], GSMA Open Gateway[20] and TM Forum[21] where telecom industry leaders are collaborating to ensure cellular network API architectures can address both digital transformation needs of consumers and enterprises as well as marketplace needs of cellular operators. The following diagram depicts inter-relationship of these initiatives and their domain of influence.

Figure 4. Industry initiatives addressing cellular network APIs[22]



3.2.1 GSMA Open Gateway

The GSMA Open Gateway[23] Initiative was launched with eight universal network APIs, including SIM Swap, Quality on-Demand (QoD), Device Status (Connected or Roaming Status), Edge Site Selection and Routing, Number Verification (SMS 2FA), Carrier Billing – Check Out and Device Location (Verify Location) functions. These APIs help to enable the basic operations required by telecoms (i.e., OSS/BSS). The GSMA Open Gateway itself is designed to allow operators to expose CSP capabilities to third-party (external) service providers in a programmatic manner through APIs, enabling interactions between different parties. Open Gateway APIs are published in the CAMARA Project.

3.2.2 CAMARA – Linux Foundation

CAMARA[24] forum brings up uniformity and abstraction guidelines to expose complex network APIs as Service APIs. This simplifies CSP complexity and enables developers and partner eco system with seamless and CSP agnostic solutions. On the other hand, this also accelerates technology adoption. There are various subgroups and initiatives that focuses on individual network services with participation across the industry that helps bridge the conversion of network complexity to developer friendly APIs, and this space is ever evolving addressing niche pain points like implementation differences across various CSPs and brings up innovative solutions like runtime restrictions.

One important use of CAMARA Service Management APIs includes CSPs' API exposure to be sold by aggregators, channel partners, or by the CSP itself using its portal, allowing further monetization of the network infrastructure. This is accomplished by customer-facing northbound APIs in the form of Service APIs, Service Management APIs, and operate APIs.

3.2.3 TMForum Open Digital Architecture (ODA)

Since APIs process data and communicate with data (as messages), a data architecture is required to address the data aspects. One such architecture specific to telecom is provided by the TM Forum's Open Data Architecture (ODA)[25]. The TM Forum develops operate APIs as part of its open APIs, but also helps organizations prepare their data management for use with its APIs for internal Operations Administration and Management (OAM). TM Forum works jointly with aggregator and developer platform owners, to facilitate their integration, and extensibility, with operator NaaS Platforms. To date, 70 open APIs facilitate the integration of the open Gateway NaaS platform with portals, marketplaces, and other aggregator platforms.

TM Forum joined the CAMARA project in 2023 to cooperatively work on gaps and an extended integrated solution to help drive NaaS solutions and create opportunities to generate new revenue.

To enable a business-first telecom network platform, the TM Forum open Operational APIs enable services to be managed end-to-end throughout the life cycle of the service. The open Gateway Technical and Business APIs allow operators to expose their CSP capabilities to third-party service providers. The CAMARA Exposure APIs complement the TM Forum and generally support building new business models through API functions such as on-demand QoS capabilities.

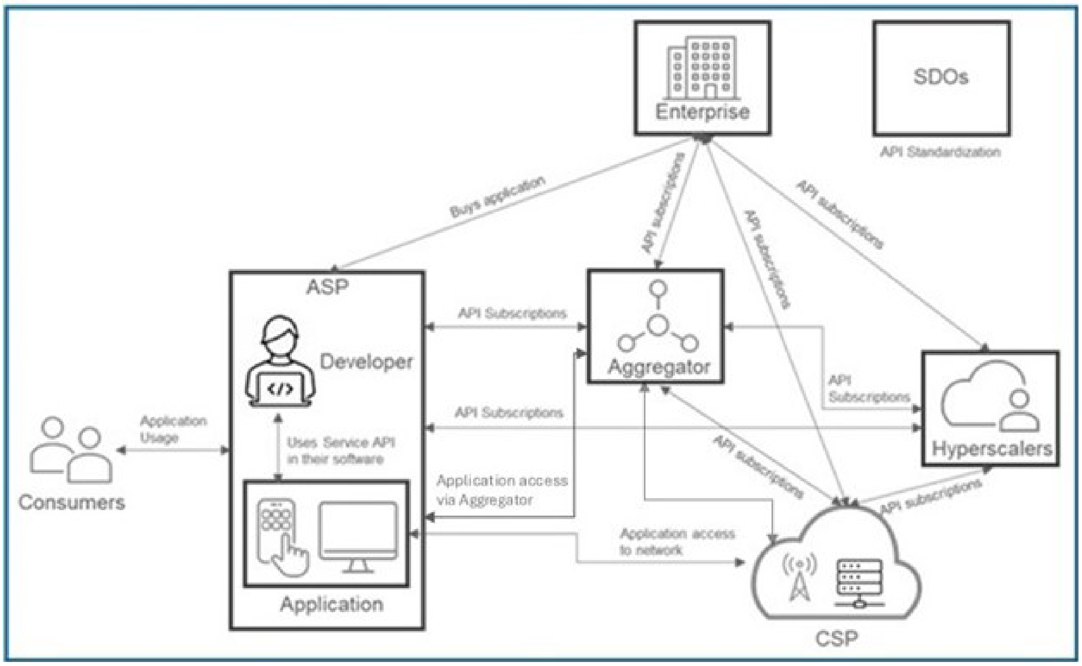
These are not the only initiatives in play, as there are other like the Bridge Alliance API Exchange[26] between CSPs and enterprise customers in Asia Pacific, CableLabs QoD API[27] for CAMARA in the United States, the 5G Future Forum (5GFF) Edge Discovery Service (EDS) API[28] for 5G and MEC, and even other lateral projects like the Linux Foundation Nephio APIs[29] that helps scale 5G service delivery and seamless coordination of entire networks by leveraging configuration as data principles.

When used together, many of the initiatives discussed drive business and performance outcomes with fit-for-purpose designed APIs.

4. Network API ecosystem

According to Britannica[30], Ecosystem is defined as “the complex of living organisms, their physical environment and all their interrelationships in a particular unit of space”. Applying this definition to network APIs, the programmable network ecosystem consists of several key players, each with their own roles and responsibilities, working together to design, build, operate, and maintain the programmable network infrastructure. The interdependencies, give and takes, of the players allow them to benefit from the broader ecosystem such as to result in the whole being more than the sum of the parts. Below diagram shows the relationship between different ecosystem players:

Figure 5. Network API Ecosystem[31]



The programmable network ecosystem comprises following key players,

- **Users or Consumers** are individuals, enterprises, or organizations that consume applications which are network aware.
- **Application Service Providers** (**ASP**) provides applications and related services to individuals, enterprises, or organizations.
- **Communication Service Providers or CSPs** are the entities responsible for deploying and managing the programmable network infrastructure. They expose the network capabilities as APIs to be consumed by applications developed by ASPs.
- **Developers** create software applications for ASPs and use the APIs exposed by the CSPs in their software.
- **Aggregators** are API providers which provide access to multiple APIs from different CSPs. These aggregators simplify the process of discovering, integrating, and managing APIs for developers and enterprises by offering a centralized hub where they can access a wide range of APIs with consistent interfaces and documentation.
- **Hyperscalers** are API providers like API aggregators providing access to multiple APIS from different CSPs. They offer comprehensive API management tools and integrate APIs with other cloud services, fostering innovation and simplifying development.
- **Network Equipment Vendors** supply the hardware and software components needed to build the programmable network infrastructure.
- **Standard Development Organization** (**SDO**) establish common languages and protocols to ensure interoperability within the programmable network ecosystem.

In addition to the various complex dependencies within the network API ecosystem, it is worth noting that just as their biology counterpart, is a constantly evolving system where the balance is realized when all the stakeholders have to benefit and thrive.

4.1 Security Considerations – roles of API gateways

Security considerations for API exposure are crucial to safeguard sensitive data and ensure the integrity of systems. Implementing strong authentication mechanisms, such as OpenID Connect[32] built on OAuth 2.0, helps verify the identity of clients accessing the API. Additionally, enforcing authorization controls ensures that only authorized users or applications can access specific resources and perform permitted actions. Employing encryption protocols like HTTPS protects data in transit, while data validation and sanitization prevent injection attacks and data tampering. Regular security audits, monitoring for anomalies, and robust logging mechanisms aid in detecting and mitigating security threats promptly.

CAMARA, as part of the commonality's repository, describes and documents common guidelines for CAMARA APIs, providing comprehensive guidelines for security considerations of Service API exposure. Adhering to these guidelines ensures a comprehensive approach to API security.

4.2 Policy and regulatory considerations

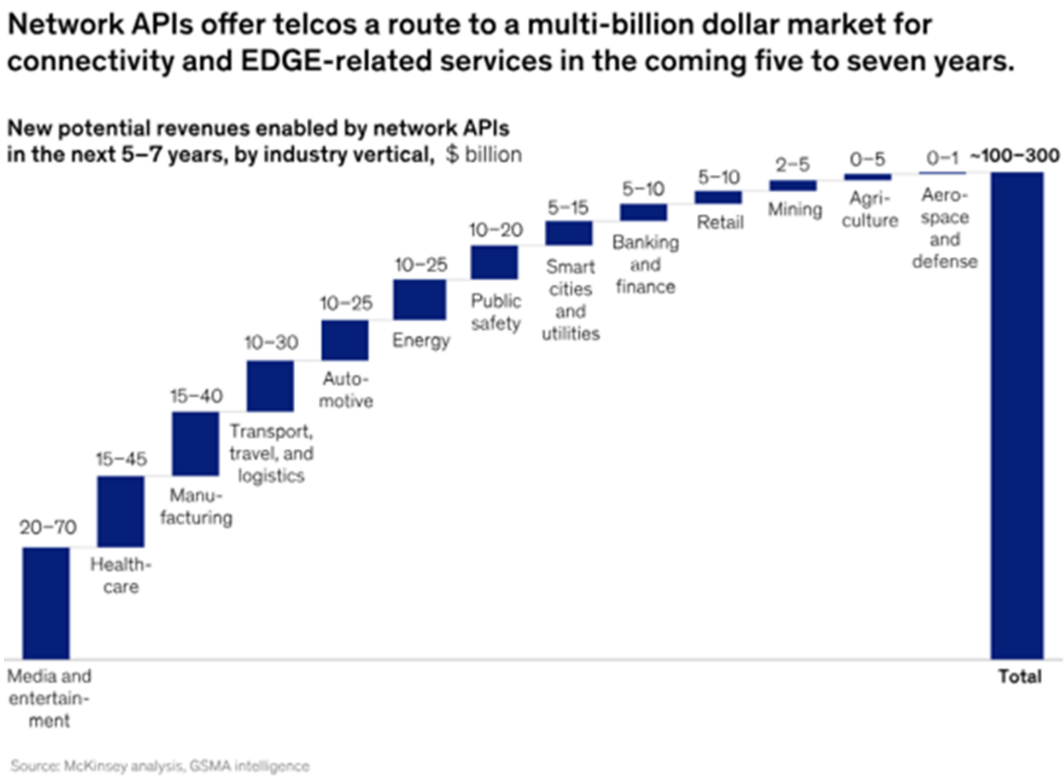
Cellular networks are tightly controlled and operated by rules and policies that change only after in depth and complete specification, test, and even deliberation with local and if needed global public agencies. Access to these networks is under complete control of operators who not only represent a business interest but also broad public policy interests. The reason for this tight control is of course the massive scale and complexity of cellular networks, and equally massive implications of service disturbance that can result by changes to behavior of these networks. Programmability in the context of these public cellular networks has to be considered with extra care and diligence.

Application developers expect the experience of accessing and creating applications through these new network APIs to be similar to using communications APIs via Communications Platform-as-a-Service (CPaaS) capabilities such as SMS, chat, voice or video calls. By evolving CPaaS to a network platform that also offers broader network APIs, service providers can unlock opportunities to monetize their network investments and empower millions of developers and enterprises to easily create enhanced applications and services. CPaaS APIs have paved the way for application developers, and as such if new services are created to be as easily accessible as legacy CPaaS then we can see fast expansion of new services. Nevertheless, there is still work to be done to arrive at a similar level of "ease of use" when it comes to advanced 5G services.

5. Opportunities & challenges

Mckinsey's[33] projection that over the next five to seven years, the network API market "could unlock around $100 billion to $300 billion in connectivity- and edge-computing-related revenue for operators while generating an additional $10 billion to $30 billion from APIs themselves," is testament to the large potential that can be realized. However, as with many other aspects of telecom technology and business, reaping these benefits will only happen after a great deal of development and evolution. In this section we review some of the challenges.

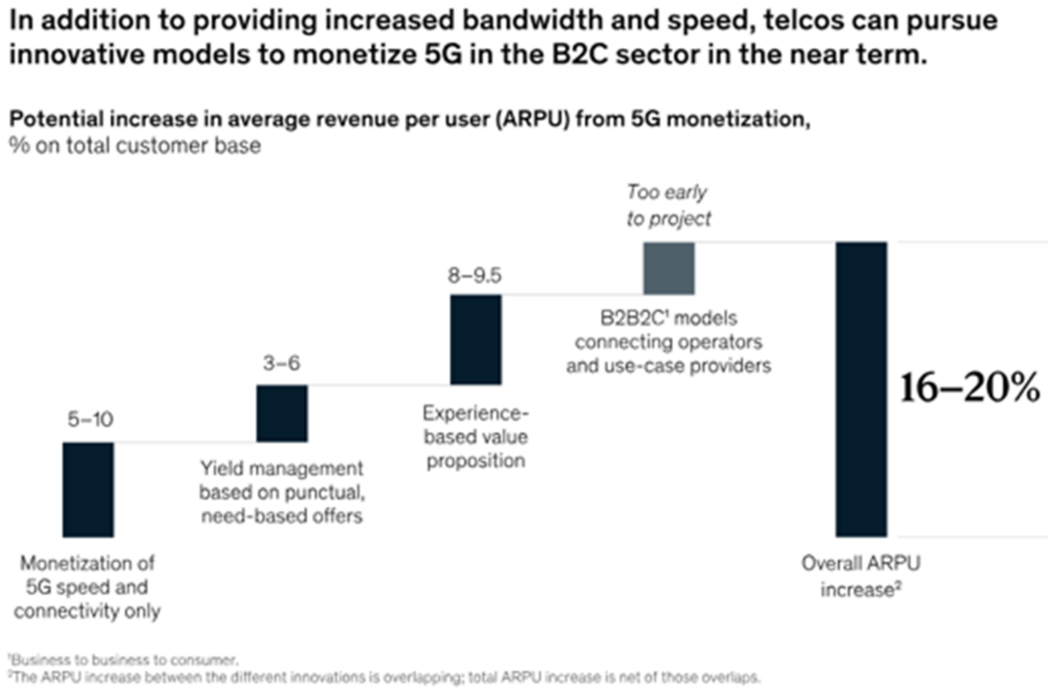
Figure 6. Five to ten years Projected Industry Revenue[34]



5.1 Emerging business models and business entities

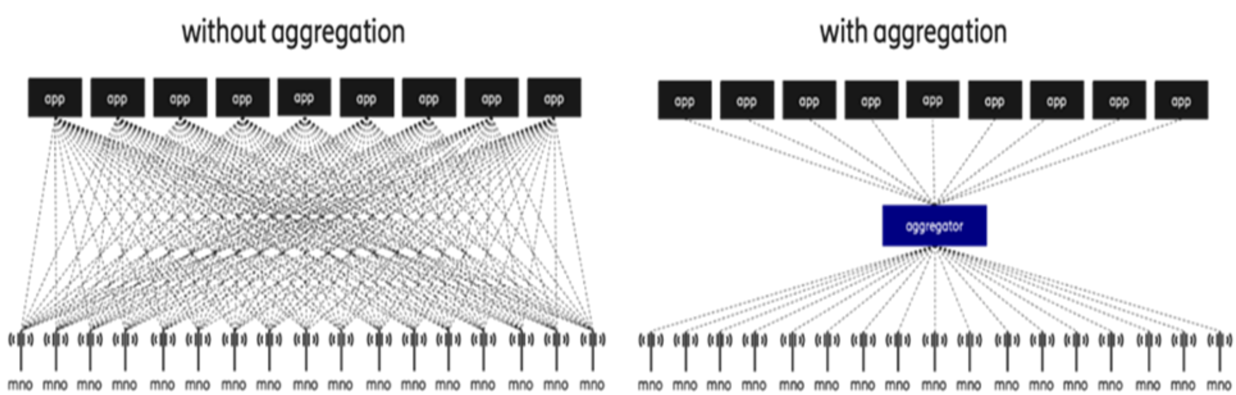
The ability to expose more granular functionality via APIs allows network operators to creatively bundle services tailored to specific use cases and markets, going beyond and in addition to their existing consumer offers. B2C offers can continue with enhanced and more advanced 5G capabilities such as QoS or network slicing, and new B2B2C services can be delivered on demand or based on premium subscription with either untapped capacity or new expansion. With pay as you go offers and provisioning just-in-time services on demand, both consumers and enterprises can leverage CSP resources without disturbing existing CSP consumer business. To this end there has been a refresh of ISVs offering solutions utilizing new capabilities across various network operators.

Figure 7. Potential 5G Monetization Opportunities[35]



The CSP API ecosystem experiences a significant simplification with introduction of an aggregator who takes the burden of centralizing and simplifying both technical and commercial relationships between CSPs and Application Service Providers (ASPs).

Figure 8. Minimizing Complexity Through Aggregation[36]



While the network operators nurture the refreshment of the API ecosystem, app developers and ISVs have a key role to play by building compelling, easy to use applications and SDKs to expand the reach of the API ecosystem. The rise of reusable SDKs will pave the way to extended reach and use of the network capabilities and at the same time leaving room for nuanced customizations that individual enterprises and applications would want to leverage to their own business needs.

5.2 Drive for uniformity

The primary challenges for CSPs to expose network functions are several but one can be attributed to the absence of globally accessible uniform APIs that can allow applications developers to use multiple and diverse CSPs' network capabilities with ease and at scale. Application Service Providers (ASPs) and developers need, and demand, APIs that seamlessly operate across all CSP networks to which their customers are connected. APIs offered by only a limited number of CSPs are less useful and will limit the scale, especially in the B2B2C model. The standard CPaaS "any-to-any" model where the API user and the target user do not have to be the same nor managed by the same enterprise is the ideal model for extended new APIs. In interactions with ASPs, interest significantly increases when an API covers more than 70% of subscribers within a specific country.

Furthermore, having ubiquitous exposure across most CSPs is not enough. Even if all CSPs were to offer the same API, applications still need to navigate the intricate process of technical integration with each CSP individually, as well as establish separate commercial relationships with each of them. This represents a challenge for any business, given the vast number of CSPs worldwide, numbering in the hundreds. Consequently, for most applications, this complexity poses a significant barrier to success.

5.3 Timing of new offers – catch 22

For a healthy ecosystem to thrive, it is important to exit the "catch 22" of supply and demand where operators will only offer a service if there is enough demand, and where application developers will only develop if a service is offered. Breaking this cycle requires nurturing deeper relationships between the operators and enterprise developers, integrators, and independent developer communities.

Global scale and success of the CSP industry in making mobile telephony (voice, SMS, MBB) a global success connecting more than 8 billion people worldwide is a fact. These services have been widely utilized by CPaaS (Communications Platform as a Service) players where any web developer can send SMS and initiate a voice call with just a few lines of code provided by every CSP worldwide. While the first SMS was sent in 1992, the widespread adoption of SMS APIs (Application Programming Interface) began in the mid to late 2010s when CPaaS took off. We as an industry cannot afford to wait so long for network APIs to reach the desired scale and ease of use similar to SMS. To speed up adoption of extended new APIs it is essential first promote new capabilities in the developer community, and second to continue to simplify API usage to match ease of use of legacy features such as SMS.

Vast majority of Application Developers and Application Service Providers (ASPs) are not familiar with 5G set of APIs and in fact do not think of innovations coming out of the CSPs. Also, it is still challenging for developers to utilize 5G functionality beyond plain enhanced Mobile Broad Band (eMBB) connectivity since they are complex, difficult to access and lack global conformity. Consider a scenario where a brilliant new idea to be launched to society requires functionality from a 5G network. Finding skilled developers capable of utilizing 5G technology poses a substantial challenge. Even if these developers are identified, integrating with hundreds of operators worldwide and maintaining the solution becomes a complex and resource-intensive task, requiring technical integration and establishment of individual commercial relationships with each operator.

5.4 New devices and applications

Adoption of 5G in the cellular device industry is still mostly focused on connectivity of the cell phone (and simple devices such as tablets that can be considered an expanded cell phone). Behavior of more sophisticated devices within a 5G network, e.g. robots, drones, AGVs, AR/VR headsets, IoT end points, is more of an after thought. These devices are being designed mostly within an enterprise network, powered through WiFi, context. To adopt these devices and respective applications to the cellular world in a way that can optimize their use of CSP APIs and resources is work in progress.

While the operator ecosystem matures to provide expanded and rich sets of APIs, there is a huge responsibility on the device and application ecosystem to ensure the chipsets, device OS, and applications are caught up with the requirements and architectures so as to allow use of these APIs. For example, use of IMS data channel and network slicing can be built into devices proactively. The IoT market has a huge potential to move away from use case based custom hardware to more generic plug and play components that deeply integrates with network APIs. Authorization standards and consent framework need to evolve to balance out the need for expanded B2B2X market while maintaining the security and privacy measures according to the global laws. As most of the network APIs involve subscriber information, there's an increased need to establish a consent management framework with

North American requirements and regulations in mind. This means an understanding of the requirements and mapping them to digital flows especially in the complex engagement models involving aggregated services and third-party relationships with other ecosystem players.

5.5 Addressing needs of Enterprise verticals

Expansion of services of CSPs to serve enterprises ultimately requires better understanding of the problems that need to be solved in various enterprise verticals and adopting CSP services and APIs to serve these verticals accordingly. The current CSP business model is based on mass offering of simple services to large populations of end users/subscribers. To optimize their footprint CSPs assess number of subscribers that can be served for each step of expansion before installing necessary equipment. In order to serve various verticals a CSP may need to dedicate a large portion of their footprint to an enterprise and be ready to implement more demanding connectivity services such as higher throughput, guaranteed lower latency, more strict security and higher availability. Some of these requirements fall under demanding regulatory standards that may differ in various localities. Understanding the requirements and evolutionary paths of development for each vertical, and ultimately meeting the SLA requirements for each vertical at a price point that is profitable for the CSP and acceptable by the enterprise continues to be a challenge. Thankfully, improvements in cellular technology are making it possible for CSPs to be able to meet these requirements at an acceptable cost, nevertheless there is still more work to be done. In order to overcome these challenges CSP thought leaders, be it in the vendor community or service provider and standard bodies, have to engage with enterprise vertical thought leaders more deeply in order to create executable roadmaps for creation of consumable services for these verticals.

Conclusion

The telecommunication world is evolving and changing at a rapid pace due in part to the convergence with IT and adoption of software driven infrastructure deployments. Emerging service-oriented approaches to business is creating new business models with “on-demand” and “just-in-time” provisioning of mostly digital services for communications and connectivity. These transformations are mostly enabled through decomposition of legacy functions and redefinition of those functions into modern digital versions: independent software-based and standardized building blocks. APIs and network APIs in particular act as conduits for integrating various building blocks in this new digital environment. Internally they are the glue that keep an operator’s network together while maintaining separation between various complex components. Externally, network APIs act as digital contracts for network service consumers, developers and enterprises.

The telecom industry has been converging on the standardization of these APIs while also collaborating on go to market strategies to commercialize these APIs at scale. Initiatives such as GSMA Open Gateway[37], Linux Foundation CAMARA project[38], and TM Forum Open Digital Architecture (ODA)[39] are establishing blueprints for an automated and orchestrated ecosystem for network APIs.

A newly announced Joint Venture with 12 global CSPs including all three major US operators could address some of the challenges identified in this paper including stimulating demand and simplifying API offerings across multiple CSPs.

APIs are as good as the user base coverage they provide to application developers and enterprises. We need better overlap of APIs across North American Operators for broader user reach. Therefore, it is imperative to establish a framework for alignment in resonance with the market needs. To properly identify these market needs, coordinated North American events targeting specific verticals (e.g. FinTech for Fraud prevention) are going to surface the untapped demand, help the industry understand the requirements, and establish broad partnerships with vertical industries.

In conclusion, to say that this new chapter in the CSP industry’s evolution is a challenging one would be an understatement as many stars need to be aligned and some existing practices need to be revisited. For once we need to look at our existing operator competitors as partners and to our partners as competitors as they will act if the industry is not moving fast enough to seize on the opportunity.

At the same time, as an industry we are already in motion and progress is being made across the globe on consistent 5G infrastructure deployments that can enable the broad adoption of network APIs.

Appendix

Appendix A: Acronyms

2FA: Two Factor Authentication

3GPP: Third Generation Partnership

AI: Artificial Intelligence

API: Application Programming Interface

APN: Access Point Name

ASP: Application Service Providers

BSS: Business Support System

CAMARA: Linux Foundation project Camara Project – Linux Foundation Project

CAPIF: Common API Framework

CASP: Content and Application Service Provider

CCF: CAPIF Core Function

CLI: Command Line Interface

CPaaS: Communication-Platform-as-a-Service

CRM: Customer Relationship Management

CSP: Communication Service Providers

CSI: Channel State Informaiton

EDS: Edge Discovery Service

eSIM: Embedded Subscriber Identity Module

GEO: Geostationary Earth Orbit or Geosynchronous Earth Orbit

GSMA: Global Mobile Supplier Association

HAS: HTTP Adaptive Streaming

HTTPS: Secure HTTP

IMS: IP Multi-Media Subsystem

IoT: Internet of Things

IP: Internet Protocol

ISV: Independent Software Vendor

IT: Information Technology

JSON: JavaScript Object Notation

KYC: Know Your Customer

MEC: Multi-access Edge Computing

MNO: Mobile Network Operators

MWC: Mobile World Congress

NaaS: Network as a Service

NEF: Network Exposure Function

NETCONF: NETwork CONFiguration protocol

NextG: Next Generation

Appendix A: Acronyms

NF: Network Function

NFV: Network Function Virtualization

NRF: Network Repository Function

NW: Network

NWDAF: Network Data Analytics Function

OAM: Operation, Administration, and Maintenance (or Management)

OAS: Over-the-Air Synchronization

ODA: Open Data Architecture

OpenAPI: https: //www.openapis.org/

OpenID: Open ID Foundation - OpenID - OpenID Foundation

O-RAN: Open Radio Access Network

OS: Operating System

OSS: Operational Support System

PHY: Physical Layer

QoD: Quality on-Demand

QoS: Quality of Service

RA: Random Access

RAN: Radio Access Network

RIC: RAN Intelligent Controller

SB: Sub-Band

SBA: Service-Based Architecture

SBI: Service-Based Interface

SDN: Software Defined Networking

SDK: Software Development Kit

SDO: Standards Development Organization

SDWAN: Software Defined Wide Area Network

SEAL: Service Enabler Architecture Layer

SIM: Subscriber Identity Module

SLA: Service Level Agreement

UE: User Equipment

UPF: User Plane Function

VAE: Vertical Application Enabler

VM: Virtual Machine

VRAN: Virtual Radio Access Network

YAML: Yet Another Markup Language – Human readable data serialization language

Appendix B: Use Cases enabled through APIs

Here are use case details as referred to in section 3. On a broad scale, services that can be enabled through networks APIs can be organized into three basic groups:

- Connectivity as a Service: Offers Connectivity + as a capability that was otherwise used as a standard functionality of voice, SMS or Data. Examples here include – connectivity insights, location aware capabilities, SIM Swap check etc.
- Communication Platform as a Service (CPaaS) – CPaaS has been there for decades, with the standardization of APIs, there is a certain refresh of these standard communication services through the new lens of programmable network APIs
- 5G services – 5G evolution is the base of the programmable network adoption across the industry and there has been many 5G specific services that's available for innovators like QoD, Edge discovery etc today are available through network APIs

B1. Internal use cases (orchestration, automated provisioning)

With the advancement of exposable network APIs for external consumption, recent years in the industry has also seen a huge uplift in structuring and standardizing internal APIs within the network operators. Some of these examples include operate APIs like order management, catalog sync etc. through standardized TM Forum APIs.

This results in utilizing programmable network APIs for CSP's own internal use cases such as

Dynamic Traffic Engineering: Operators are utilizing network APIs to dynamically adjust traffic flows, reroute traffic during congestion scenarios, and optimize network performance based on real-time network conditions such as bandwidth utilization, latency etc.

Automated Service Provisioning: Network APIs enable operators to automated service provisioning such as network routes, QoS policies etc. reducing deployment time while keeping up with service delivery.

Product Catalog Management: Enables dynamic management of product and service catalogs, allowing for the quick introduction of new offerings and updates to existing ones.

Order Management: Facilitates the automation of order capture and management processes, including order decomposition, validation, and execution across multiple network domains.

Inventory Management: Supports the real-time tracking and management of network resources and services inventory, ensuring optimal utilization and reducing redundancy.

Service Configuration and Activation: Allows for the automated configuration and activation of network services based on customer orders, significantly reducing manual intervention and accelerating service delivery.

Fault Management: Enables the detection, isolation, and resolution of network faults, improving network reliability and QoS.

Performance Management: Supports the monitoring and analysis of network performance data to ensure service levels are met and to identify areas for improvement.

Billing and Charging: Facilitates the collection, aggregation, and processing of usage data for billing purposes, supporting flexible pricing models and real-time charging capabilities.

Customer Management: Provides a unified view of customer data across OSS/BSS systems, enhancing customer service and enabling personalized service offerings.

Partner Management: Enables the management of partnerships and agreements with third parties, supporting the seamless integration of partner services into the provider's offerings.

Resource Function Activation and Configuration: Allows for the dynamic allocation and configuration of network resources in response to service demands, optimizing network efficiency and performance.

Trouble Ticketing: Supports the creation, tracking, and resolution of trouble tickets, improving response times and customer satisfaction.

SLA (Service Level Agreement) Management: Facilitates the monitoring and management of SLAs to ensure contracted service quality and performance metrics are met.

These use cases illustrate the broad applicability and value of network APIs in transforming OSS and BSS operations. The standardization of the key interfaces enables telecommunications providers to leverage the full potential of their network capabilities, driving efficiency, innovation, and enhanced customer experiences.

B2. External use cases

While programmatic telephony use cases (communication as a service) have been in industry for decades, introduction of 5G paves way to additional custom service development like enhanced quality on a video or conference calls, remote maneuvering and operations of industrial equipment are more and more prevalent these days.

Network APIs have become integral to the operation and innovation within various vertical industries, enabling them to leverage connectivity in ways that optimize operations, enhance customer experiences, and open new revenue streams.

In healthcare, Network APIs can facilitate the seamless transfer of patient data from wearable devices and home monitoring equipment to healthcare providers, enabling real-time health monitoring and timely interventions. Quality on Demand APIs can support the delivery of healthcare services over the internet, allowing for video consultations, sharing of medical records, and remote diagnostics, thus making healthcare more accessible.

Additionally, Network APIs such as SIM Swap checks, Device Status verification may be used for fraud detection. APIs can also ensure secure and reliable communication between different financial institutions for the execution of transactions or compliance checks,

In retail space, Network APIs allow for real-time tracking of goods across the supply chain, providing retailers with up-to-date information on inventory levels, delivery statuses, and potential disruptions. By integrating with CRM systems and analytics tools through network APIs, retailers can offer personalized recommendations, promotions, and services to enhance customer engagement.

In manufacturing, APIs facilitate the collection and analysis of data from machinery and equipment to predict when maintenance is required, reducing downtime and operational costs. They enable the interconnectivity of machines, systems, and people to create highly automated and optimized manufacturing environments.

Network APIs allow logistics companies to monitor the location, status, and condition of vehicles in real-time, improving route planning and operational efficiency. Customers can receive up-to-the-minute updates on the status of their deliveries, enhancing transparency and customer satisfaction.

Another use case of data analytics is in the energy sector where reliable networking can provide monitoring and control of electricity distribution, facilitating the integration of renewable energy sources and improving grid reliability. provide businesses and consumers with insights into their energy usage patterns, helping to identify opportunities for conservation and cost savings.

Network APIs support the delivery of online learning content and services, enabling students to access educational resources, submit assignments, and receive feedback remotely. They can integrate with security systems and emergency services to enhance the safety of students and staff on educational campuses.

In each of these verticals, network APIs serve as the backbone for digital transformation, enabling industries to harness the power of connectivity for innovation, efficiency, and enhanced service delivery.

Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement of 5G and beyond toward 6G throughout the Americas.

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