FCC Technological Advisory Council (TAC)

Future Game Changing Technologies Working Group (FGCT WG)

Report on Impact of Programmable Networks

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Executive Summary

The ICT industry is undergoing an unprecedented transformation, from largely hardware-centric specialized network infrastructure statically provisioned to software-centric cloud-integrated dynamic networks, which are built to a significant degree on common general purpose server infrastructure. This transformation to software programmable networks is both *driven* by the dynamic networking needs of cloud services, and *enabled* by the rapid advances of Moore's Law-driven IT cloud technologies.

The implementation of network functions on virtualized compute infrastructure, termed Network Function Virtualization (NFV), disaggregates software from hardware, and results in many operational benefits. These cloud-based virtual network functions require automated connectivity to interconnect them, and Software Defined Networking (SDN) does this by separating the control and forwarding of the networking infrastructure, enabling automation and efficiency through greater centralization of control and optimization. Together NFV and SDN automation, coordinated via orchestration software, allow entire networks to become flexibly programmable. And that agility can be extended to external 'consumers' of the network through APIs. The adoption of these technologies and architectures in networks is well underway and accelerating, rapidly leading to a new world of programmable networks.

These developments will, in the short term, fundamentally change the ways in which networks are being built. In the longer term, programmable networks will also change the nature of how the industry is structured to deliver services in pervasive and far-reaching ways. Many of these industry changes may clash with current structures, policies, and regulatory regimes of the FCC, put in place at a time when static, monolithic, access-specific network/service providers were the only model.

Anticipating the new delivery structures, value chains and business models made possible by the flexibility of programmable networks, it is vital that the FCC's role in stimulating and maximizing US innovation-driven economic growth that the current 'regulatory architecture' be re-assessed from an end-to-end systems point of view, and adapted for future network fitness.

1 Overview

1.1 Mission Statement

The FCC Technological Advisory Council (TAC) Future Game Changing Technologies (FGCT) Working Group continued its work from 2015. The work proposed for 2016 includes the following:

i. Concentrate on identifying the technical challenges in developing 5G and what can to be done to ensure rapid deployment in the U.S;

ii. Examine potential new business models and service regimes that could be enabled by future programmable networks. The work group will also address the adoption of dynamic, virtualized networks and the implications for current FCC rules and policies;

iii. Address how the FCC can better anticipate rapid changes in technology and an approach to rules and policies that has the best outcome for the nation.

iv. Finally, the work group will continue its efforts to identify key new and emerging technologies

1.2 Scope of Work

The scope of this report is to concentrate on identifying the impact that SDN, NFV, and programmable networks will have on the industry, what implications that could have on the work of the FCC, and what can to be done to ensure that the US can fully benefit from the economic innovations that these new technologies make possible.

1.3 FGCT WG Membership

Table 1: FGCT WG Membership

Name	Organization
Adam Drobot, Co-Chair	OpenTechWorks
Kevin Sparks, Co-Chair	Nokia
Kumar Balachandran	Ericsson
John Barnhill	Genband
Mark Bayliss	Visualink
Nomi Bergman	Advance/Newhouse
Michael Browne	Verizon
Lynn Claudy	National Association of Broadcasters (NAB)
Marty Cooper	Dyna LLC
Brian K. Daly, 5G SWG Co-Chair	AT&T
J Pierre de Vries	Silicon Flatirons
Jeffrey Foerster	Intel
Dick Green	Liberty Global
Lisa Guess	Juniper Networks
Russ Gyurek	Cisco
Dale Hatfield	SGE
Steve Lanning	Viasat

Name	Organization
Chenghao Liu	Samsung
Brian Markwalter	CEA
Lynn Merrill	NTCA
Paul Misener	Amazon
Jack Nasielski	Qualcomm
Ramani Panduragan	XO Communications
Charla Rath, 5G SWG Co-Chair	Verizon
Mark Richer	ATSC
Hans-Juergen Schmidke	Facebook
DeWayne Sennett	AT&T
Marvin Sirbu	SGE
Paul Steinberg	Motorola Solutions
Michael Tseytlin	Facebook
Charlie Jianzhong Zhang	Samsung

2 Defining 'Programmable Networks'

Tremendous strides have been made over the past few decades in improving the capacity, utility and cost effectiveness of telecommunications networks. Digitization followed by IP convergence, coupled with massive hardware and software innovations, have allowed networks to become highly versatile multi-purpose shared resources powering global economies.

Now, ever more powerful general purpose computing, cloud virtualization, and software-defined control technologies are taking this multi-use paradigm to a whole new level – rapid and flexible composition and reuse of the component 'building block' resources of the network. Programmable networks are the natural culmination of this transformation, assembling these flexible network building blocks – network functions and interconnections together – into virtual network constructs dynamically and automatically under programmable software control.

Many virtual networks can be hosted on the same physical network, using slices of the resources of that network for specific usages. This can be used within the network entity to carve out optimized virtual network slices for different service types. It can also be used by other entities, accessing the network resources via programmable network APIs, to operate as a virtual network operator or to implement localized service delivery functions close to end users.

3 The Technologies Underpinning Programmable Networks

Several emerging technologies have helped to realize the flexibility and programmability of the network infrastructure which are captured in the following table.

Powerful	The advances in manufacturing technology via Moore's Law has created

standard high-volume (SHV) servers	powerful multi-core standard off-the-self servers capable to processing various network traffic in real-time. Platform architectural advances and accelerators are continuing to rise, keeping up with expected traffic growth rates. Today's SHV servers are capable of supporting up to ~200-250Gb/s (64 byte packets), depending on packet processing and traffic management complexity, thus able to perform nearly all control and very many of the data plane functions in the network.
Virtualization Technology (VT) / Virtualized Machine (VM)	VT enables multiple functions and services running on SHV servers so that the platform resources (processing power, storage, I/O, etc.) could adapt to a given workload and be reconfigured over time and can be treated as a standalone VM. VT provides a key advantage for telco/service providers in the area of networking by enabling this multi-purpose platform to one day run virtualized firewalls, the next day virtualized NAT, EPC, and so on. A single high volume platform will run any virtualized networking workloads thus reducing needs for specialized equipment.
Network Function Virtualization (NFV)	NFV is a network architectural concept that was conceived by telecommunications operators and standardized in collaboration with their equipment suppliers. NFV is being standardized in ETSI to accelerate network infrastructure transformation. NFV aims to implement network functions, e.g. routing, firewall, cellular service gateways (S-GW) & packet gateways (P-GW), etc. as software functionality running on SHV servers as opposed to tightly integrated software/hardware functionality on dedicated hardware platforms. NFV utilizes a programmable data plane managed by an SDN controller and coordinated via an orchestrator (e.g., OpenStack or others) to schedule (e.g. OpenStack Nova) or position the network functions on the SHV servers at run-time either individually or as composable functions in a chain (i.e., service chaining).
Software Defined Networking (SDN)	SDN is a networking architecture which provides the separation of control and data path with programmability of the network exposed to end users through APIs. This ability to create a programmable control plane operating independently of the data plane enables a centralized view of the network, independent scaling of the control plane and improves network utilization, enhances performance, and offers agile operation enabling deployment of new services.
Open source SW	Today there are significant open source efforts in all areas of networking which help to create the foundation on which NFV and SDN solutions can be build. These including the following (not exhaustive): • ODL: OpenDaylight • ONOS: Open Network Operating System • OPEN-MANO: Open Management and Network Orchestration • OPEN-O: Open Orchestration • OPNFV: Open Platform for NFV • OvS: OpenVSwitch

	• OvS/DPDK: DPDK based OvS • DPDK: Data Plane Development Kit • BESS: Berkeley Extensible SW Switch On-going standards: • ETSI NFV Reference model and reference usage model • ETSI Specification on Security

4 The Transformational Potential of Programmable Networks

The transition toward programmable networks has already begun, although the full transformation of networks will take time, as the types and scope of changes to the way networks are implemented are multi-dimensional and pervasive. But the impact to the utility and operational efficiency of networks will be similarly profound and disruptive. By enabling the resources of the network to be assigned and re-assigned to different uses and different users, it will lower the time and cost for both operators and 3rd party entities to experiment and innovate new services, new devices, new applications … and innovative the new business models that will drive the next wave of digital value creation.

Adopting cloud technologies into the implementation of the network enables the same types of dynamic innovation and economic benefits that the cloud has brought to Internet applications, but extends it to the networking domain and for new types of high bandwidth and/or low latency applications requiring localized service delivery via distributed virtualized 'edge clouds'. Indeed it is cloud-based application and content providers and cloud-enabled enterprises that drive the need for these dynamic on-demand 'network-as-a-service' (NaaS) offerings. Thus the disruptive potential of the programmable networks transformation is analogous to – and integrally linked with - the cloud revolution that spawned it.

While it is clear that this will fundamentally change the way individual networks are internally implemented, it is especially important for the FCC to consider how programmable networks and the new business models they enable could change the structure and dynamics of the ICT industry. In this regard, the types of industry level shifts made possible can be characterized as four dimensions of change, as illustrated in Figure 1 and described below:

1) **Convergence** –The drive for orders-of-magnitude scaling of wireless access, the desire for most services to have some level of mobility, and the use of network virtualization to facilitate the restructuring of the network (both access components and a new access-agnostic service core) all serve to promote the convergence of wireline and wireless networks. Services can be offered independently of access type, and provided over multiple access types/technologies – often simultaneously to maximize the throughput, reliability of connectivity, and continuity of context of the user experience. This represents a significant change for policy architects relative to the access-type specific regulatory structure in practice today.

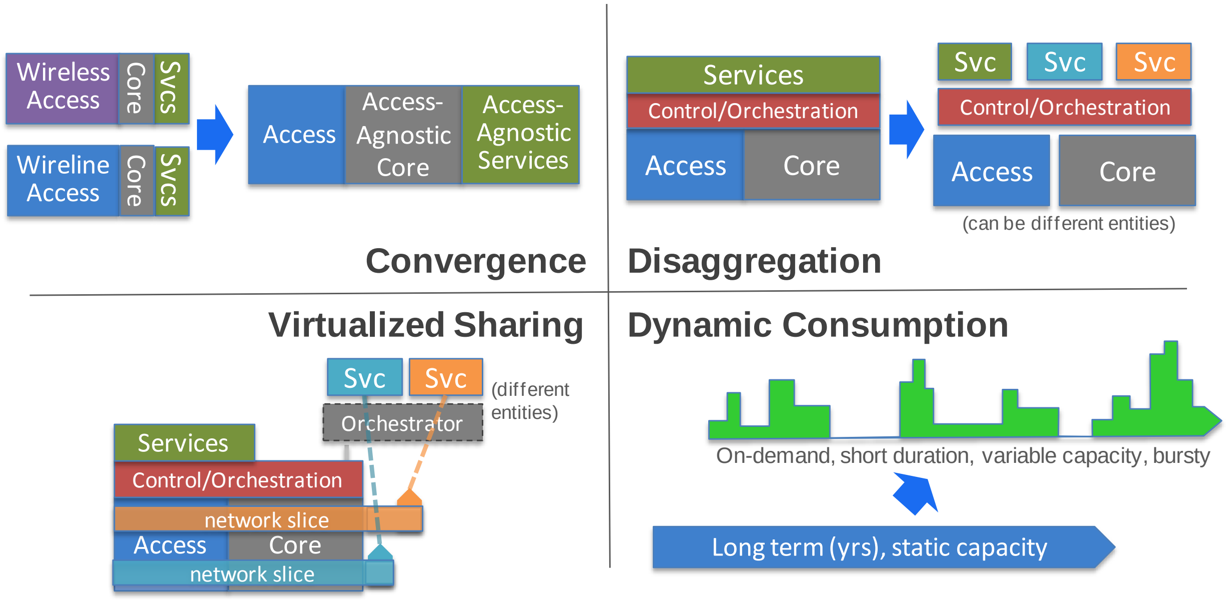

Figure 1 - Four dimensions of change enabled by programmable networks

2) **Disaggregation** – With the decoupling of access from services, and the disaggregation of network functions into modular virtualized software modules, large blocks of the service delivery chain can be modularized. These blocks may be provided by different entities, in effect creating a disaggregated value chain. For example, a global service provider may utilize multiple regional networks, each leveraging separate cellular and unlicensed access networks in a coordinated way. While a complete and granular disaggregation of network/service roles is not anticipated, and many services will likely continue to be offered by a single entity, such disaggregated value chains are likely to make economic sense for specific applications.

3) **Virtualized Sharing** – Many of the functions of networks will be implemented in virtualized software running in virtual machines (VMs) or containers on general purpose computing hardware that are part of a multi-tenant cloud environment. These hardware resources will be shared and reused for many purposes. Likewise, software-defined connectivity overlays, viz. tunneled sub-networks, allow for flexible multi-tenant sharing of connectivity resources. Combined, these multi-tenant capabilities allow creation of 'network slices' which are end-to-end compositions of network resources isolated and devoted to a particular use. These network slices can be used by the network operator to optimize for different types or classes of services, or they can be offered as a 'network-as-a-service' to other entities to implement some of their internal or service delivery needs. This is especially powerful when functions need to be localized near end customers for performance and efficiency reasons. Both virtualized sharing and disaggregation will result in some service-related functions – even local ones – not always being under the direct control of the access provider. This will have implications for how regulatory-related roles and obligations are applied.

4) **Dynamic Consumption** – The final dimension relates to time. Control over multi-tenant shared resources requires a centralized view of network resources and the ability to

allocate these resources accordingly. With the scale of transactions from disaggregation and multi-tenancy comes the necessity to automate the operations of the network, and this automation will be used for network-aaS slices as well. Thus, these new network slices can be dynamically 'consumed' as needed - instantiated, scaled, and de-instantiated on potentially very short time cycles (minutes vs. weeks/months). Manual FCC approval and registration processes, if and when required, would likely diminish the value of these new types of dynamic network consumption and new service creation.

It is important to keep these new dimensions, which are in effect new structural degrees of freedom, in mind when considering the type of new services, new models of content and application delivery, new forms of industry structure – and how these waves of innovation might impact the work of the FCC (and other government agencies). We see these new models lowering the time, investment, and risk for new virtual operators, performance-intensive applications providers, and enterprises in general to experiment, adapt, and scale up quickly. In turn, this virtualized network sharing paradigm creates new opportunities for efficiency and return on network investment.

5 Programmable Networks Use Cases

Programmable networks will open many opportunities for innovative use cases. While there are many ways for network operators to use this flexibility to provide their own services within the perimeter of their networks, our focus is on use cases involving multiple entities in the delivery of content and services, as these are the cases that are most likely to impact FCC policy and regulatory regimes.

Table 2 summarizes a representative set of example use cases that were assessed for their potential impact on the industry and on the various roles, responsibilities, and objectives of the FCC.

Table 2: Programmable Network Use Case Analysis Summary

Case	Description	Significance	Potential FCC Impacts
Localized Mobile Operator Roaming	Home operator places own localized service function software in roaming network via network APIs	▪ Uniform service experience ▪ Local delivery performance ▪ Reduced transport & peering	▪ Distribution of access obligations ▪ Fluid operations across borders
IoT Vertical Appl. Provider: Video pre-processing	Video surveillance appl. provider instantiates local video recognition pre-processing in local network cloud	▪ Allows efficient mass scale high resolution surveillance ▪ Reduced Internet congestion	▪ Mix of Internet & special service ▪ Potential for conflicts with open internet

Case	Description	Significance	Potential FCC Impacts
Low latency services & the tactile internet	5G promises 1 msec round trip latency and 99.999% reliability for the radio link towards enabling time critical, interactive applications including autonomous vehicles, AR/VR, Industrial automation/robotic control, eHealth/remote surgery, etc.	▪ Enables new applications and business opportunities ▪ Significant societal impact from new applications improving personal health and safety ▪ Requires computation closer to the edge of the network	▪ May require prioritization or interrupt capability in the network or at edge (potential for open internet conflicts) ▪ May require 3rd party SW/services running at edge (security issues?) ▪ Additional/dedicated spectrum for mission critical applications?
Converged wireless & wireline carrier	Increasing wireless speeds bring parity between wireless and wireline services with added dimension of mobility for wireless services. Services delinked from access/transport mode	▪ Consumers access platform independent services ▪ Service continuity from home environment to mobile environment: services follow consumer	▪ Traditional view of wireless/wireline carriers blur ▪ Potential reorg of wireless/wireline companies with focus on services not platform ▪ Single platform companies at increasing competitive disadvantage
Network slicing for providing QoS	In a virtualized network environment, a logical 'slice' of a network, dynamically assigned network assets, can support a service type within a telecom provider or be offered as a service (i.e. network aaS) to other companies for their own use or to provide end user services	▪ Lowers telecom capital cost as capital assets now shareable among multiple applications and customers ▪ Telecom services can be integrated into other applications ▪ Different slices can be configured for different services: e.g. consumer voice communications, high assurance, low latency connections, etc.	▪ Blurring of lines between telecom and application providers ▪ Access to restricted telecom resources might need to be extended: e.g. E.164, 911 services, etc ▪ Critical consumer information may be known only to appl. provider: may complicate public safety services ▪ Security issues may be created through altered attack surface

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Enterprise Use Cases	Deep integration of internal processes across the enterprise exploiting mobility and timely data services and analytics. New customer facing functionality through embedded multi-mode communications to provide ubiquitous access to services.	▪ Driver for innovation and productivity gains by enabling novel ways of conducting business and enabling new business models. ▪ Lowering the cost, time, and complexity barrier for the introduction of new services and offerings ▪ Accelerating the convergence of comms, IT, and operational technologies	▪ Movement of more critical services to employ public networks and greater reliance on such networks for the Nation to conduct its business. ▪ A much greater dependence on the reliability and availability of networks and a greater blending of domains not traditionally part of the FCC's charter.

Even from this short selection of use cases, it is clear that programmable networks (1) has the potential to drive significant innovation, competition, and economic activity; and (2) that the areas of impact on the FCC are likely to be many and varied, if it is to fulfill its role in spurring this innovation and securing its benefits for the US.

6 The FCC and Programmable Networks - Impacts and Considerations

As illustrated by the use cases outlined in section 5, there are many new service delivery structures and corresponding new business models we can envision which are made possible by programmable networks. Just as important, the instantiation, expansion (in size and geography), and de-instantiation of these service models will in many cases be dynamic – automated very similarly to the way that cloud applications utilizing general cloud service providers are today.

The new models now made possible by programmable networks will challenge the current structure and processes of the FCC. Specifically the following areas are among those anticipated to be impacted:

Regulatory Structure – As the distinctions between wireline and wireless networks blur, the structure of regulations and staff will need to move away from access technology defined silos (cable, wireline, wireless, etc.) and to a more inter-connected model reflecting the variety of new service delivery architectures. A converged communications service seamlessly mixing fixed, fixed wireless, mobile, and/or satellite connectivity would need to allocate service-related obligations in a common access-agnostic way.

Entity Classifications - Definitions of communications service entities regulated by the FCC and corresponding rights and obligations (e.g. 911/PSAP access, number assignment, SS7 access, legal intercept) may need to be flexibly assigned according to functional roles in disaggregated service delivery chains. Local service functions necessary for some of these obligations, which previously were always owned and operated by the access network provider, may now be *instantiated* locally within that network but actually leased and operated by a different entity providing the content and/or service.

Process Dynamics – Processes for establishing services and for incremental expansion of provider footprint (spectrum, capabilities, geographic scope) will need to be streamlined and dynamic (i.e. portal/API-driven automation), in order to unlock the value of network programmability. It will create little to no value to be able to turn up a new service capability or a new location in a matter of minutes, if there is a gating manual FCC approval step requiring weeks or months.

Tactile Internet QoS – Extremely low latency and mission critical services may require prioritization (even though otherwise an Internet service), or even dedicated/ preemptory access to spectrum. This could blur the lines between Internet and special services.

Security – Programmable network slices may have greatly improved security properties from SDN automation tools. They also introduce additional security aspects to address, due to an altered attack surface and larger scope of control exposure to the external ‘consumers’ (typically entities rather than individuals) of programmable network slices.

All of these are areas where innovation-driven economic growth can be held back in the US if slow or inflexible policy and/or regulatory regimes inadvertently obstruct them. The impact areas identified above should not be viewed as an exhaustive list; it is quite likely that a deeper assessment – as well as the emergence of new business model innovations yet unforeseen – will reveal more challenges for the work of the FCC.

7 Recommendations for Programmable Networks

Given the rapidly changing technologies and architectures for implementing networks, and the blurring of lines between clouds and networks, it has never been more important for the FCC to develop a thorough, up-to-date, and end-to-end systems view in understanding the moving parts in this sweeping industry transformation. This should be viewed as a prerequisite for adapting the FCC in front of – rather than in reaction to – the challenges that these innovative SDN/NFV/cloud-driven future networks will present.

Recommendation: **Future End-end Systems Excellence Program -** The FCC should build upon the 'FCC University' foundation to establish a concentrated 'excellence' program focused on future end-end networks & systems, combining targeting staff training and subject matter expert (SME) augmentation with regular structured workshops to harvest the latest industry and other agencies insights and expertise (including academia, NGOs, and other appropriate stakeholders).

Anticipating the new delivery structures, value chains and business models made possible by the flexibility of programmable networks, as described in sections 4 and 5 above, is key to sustaining the FCC's role in both furthering societal needs and in stimulating and maximizing US innovation-driven economic growth. As laid out in section 6, the new models now made possible by programmable networks are expected to challenge the current structure and processes of the FCC. Therefore it is vital that the FCC's current 'regulatory architecture' be regularly re-assessed and adapted for future network fitness.

Recommendation: **Critical Assessment of Regulatory and Policy Architectures -** The FCC should embark on a comprehensive assessment of the fitness of FCC processes, systems, and structure for the emerging programmable network future. This should be informed by many inputs, including the reports of the 2016 TAC FGCT WG, the future end-end excellence program recommended above, and the insights learned from annual facilitated study exercises, proposed by the FGCT WG separately. To accomplish the re-assessment the FCC should form a cross-organization multi-stakeholder taskforce that is focused on continuous adaptation. The purpose of the taskforce is to create a plan of actions needed to align the architecture of the regulatory framework in keeping with emerging developments in technology, usage patterns, and business models.

The FGCT WG views these recommendations - to understand, assess, and actively plan for a programmable network future - are vitally important to ensuring the Nation gains the full benefits of the emerging 'next level' digital economy.

Appendix A: Glossary

3GPP	**Third Generation Partnership Project** www.3gpp.org
5G	**Fifth Generation**
API	**Application Programming Interface**
CTIA	**Cellular Telecommunications Industry Association** www.ctia.org
ETSI	**European Telecommunications Standards Institute** www.etsi.org
FCC	**Federal Communications Commission** www.fcc.gov
FGCT	**Future Game Changing Technologies**
IEEE	**Institute of Electrical and Electronics Engineers** www.ieee.org
ICT	**Information and Communications Technology**
NFV	**Network Functions Virtualization**
NGO	**Non-Governmental Organization**
PSAP	**Public Safety Access Point**
SDN	**Software Defined Networking**
SHV	**Standard High Volume (servers)**
SS7	**Signaling System 7**
TAC	**Technological Advisory Council**
VM	**Virtualized Machine**
VT	**Virtualization Technology**