AUTONOMOUS NETWORKS: NOW IS THE TIME

BACKGROUND

Communications service providers' (CSP) networks are large and complex with multiple interworked technologies requiring numerous skill sets and tools to manage effectively, including planning, installing, analyzing, assuring, and securing them. To manage and evolve their networks, CSPs typically divide their deployment into domains, often defined by technology (such as optical transport, IP/MPLS or carrier Ethernet), by service (such as SD-WAN or residential broadband), by geography (access, metro, core, long haul, ultra-long haul) or along other organizational boundaries. Each of these domains are the responsibility of a separate group of people (although some people and groups transcend the boundaries to be multidomain) and often have their own sets of procedures and OSS systems to support them. A tiered OSS structure has evolved that seeks to automate provisioning and assurance within a domain (using domain-oriented controllers and applications) as well as across domains (using cross-domain functionality, also called orchestration software). Because of the needs to look at a network as a whole, the assurance function often in intrinsically multidomain and happens at a network level, while service provisioning is broken down into its constituent domains and done in each domain with orchestration of the process in an order management system. Resource provisioning (network augmentation and optimization) is usually done at a purely domain level with much manual work. Meanwhile, the increasingly virtualization of the network elements has led to the creation of a new domain, the telco cloud, providing the computing, storage, and communications infrastructure for these new elements.

But as the network elements become virtualized[1], more standardized, and more intelligent and as the industry moves to a 5G era, the opportunity exists to reimagine the way we are planning, implementing, and managing networks. The TMForum Autonomous Networks vision[1] is one such reimagining.[1]

This article describes market needs, asks the question why this vision (which has been around for many years) is now ripe for realization, and discusses some of the challenges ahead of the industry as we strive toward autonomous networks.

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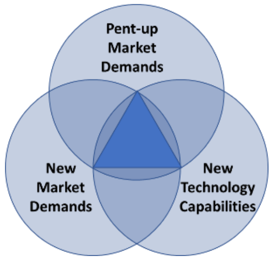
MARKET NEEDS

As is usually the case, major new trends are born through the intersection of three things: pent-up market demands, new market needs that spur the market to invest in new approaches, and new technological capabilities. In this section, we identify these items at high level.



Pent-Up Market Demands for Higher Customer Satisfaction and Revenue Growth

For as long as any of us remember, the Net Promoter Scores (NPS) for Communications Service Providers (CSP) have been poor. Customers rate them usually near car-rental companies, often in the range of zero (as many promoters as detractors). This has persisted, even in the face of major investments by CSPs and as customers' expectations have risen overall.[1]

New Market Demands

Although network usage has grown at a furious rate for 20 years, the rate of revenue growth has slowed as competition has increased and the need for continually escalating investments has continued.

> The goals of autonomous networks are not new but are what CSPs need to meet the increasing needs of enterprises and consumers and to complete their journey to become DSPs.

Enterprises

The pace of enterprise digital transformation has increased greatly with the recent changes because of Covid-19, with transformation proceeding at over 20 times the rate previously[2].

As industries seek to implement the Industry 4.0 vision, becoming composable enterprises[3], they must undergo a full digital transformation of their company processes and their IT computing, storage, and processing infrastructure. They also require a new vision of their communications infrastructure to provide the enabling rapidity, composability, and flexibility. ACG Research has envisioned the creation of an Intelligent Composable Fabric.[4] This fabric brings together the communications, information, data processing and storage, operations technology, and process automation technologies that are needed to compose a digital platform for a wide range of enterprises as they undergo their digital transformations.

Key to providing this infrastructure is an integrated, highly flexible, exceptionally reliable, self-service, autonomously managed communications platform that can be deeply integrated with information

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[1] See, for example, https://www.gartner.com/en/newsroom/press-releases/2020-01-15-gartner-says-74--of--customer-experience-leaders-expe

[2] See, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever.

[3] See, for example, *Future of Applications: Delivering the Composable Enterprise*, Gartner, 11 February 2020.

[4] Parker-Johnson, Paul, Private communication, ACG Research, November 2020.

processing and storage to meet the evolving needs of the enterprise. Autonomous networks (AN) would meet these criteria.

Consumers

The needs of consumers have recently greatly expanded with massive work at home programs. Consumers now require not only to be connected to their friends and family, local businesses, entertainment providers and the global internet service providers, but also to corporate resources. The criticality of these services is pushing the ability of the networks to provide the bandwidth, user security, and corporate-level reliability required.

Operators

Network operators now compete not only with each other, but with web-scalers, infrastructure vendors with Network as a Service offerings, and new entrants, such as Rakuten, for whom communications is one of many services. These new breed of service providers are starting from a clean slate, with modern, virtualized technology, and a low-cost, fast-moving mindset. In response, CSPs have recalibrated their desires, moving from the traditional mind set of 10% to 20% operational improvement per year to a vision that ACG Research calls the *10xNetwork*, seeking an order of magnitude improvement in operational costs, capital costs, rate of new services introduction, and scalability.[5]

New Technologies that Offer New Approaches

As will be detailed later in this paper, the availability of inexpensive massive computing and storage technology has enabled web-scalers, such as Facebook, Amazon, Netflix, and Google, to re-engineer software architecture, development, delivery, and support. Meanwhile, automation technology, including new artificial intelligence and machine learning capabilities, have advanced considerably while software coding skills are being democratized through the availability of sophisticated open-source software, higher-level specialized languages, and low-code/no-code solutions. These technological advances are enabling the industry to do things unimagined just a decade ago.

[5] See Mortensen, Mark, *The ACG 10xNetwork Project*, https://www.acgcc.com/blogs/2020/05/18/acg-10xnetwork-project/.

OPERATIONS VISION OF THE FUTURE: AUTONOMOUS NETWORKS

Autonomous networks provide an operations vision for networks of the future, provided either as a service or as a platform to enterprises as defined by the TMForum, providing the Zero X experience, Figure 1.

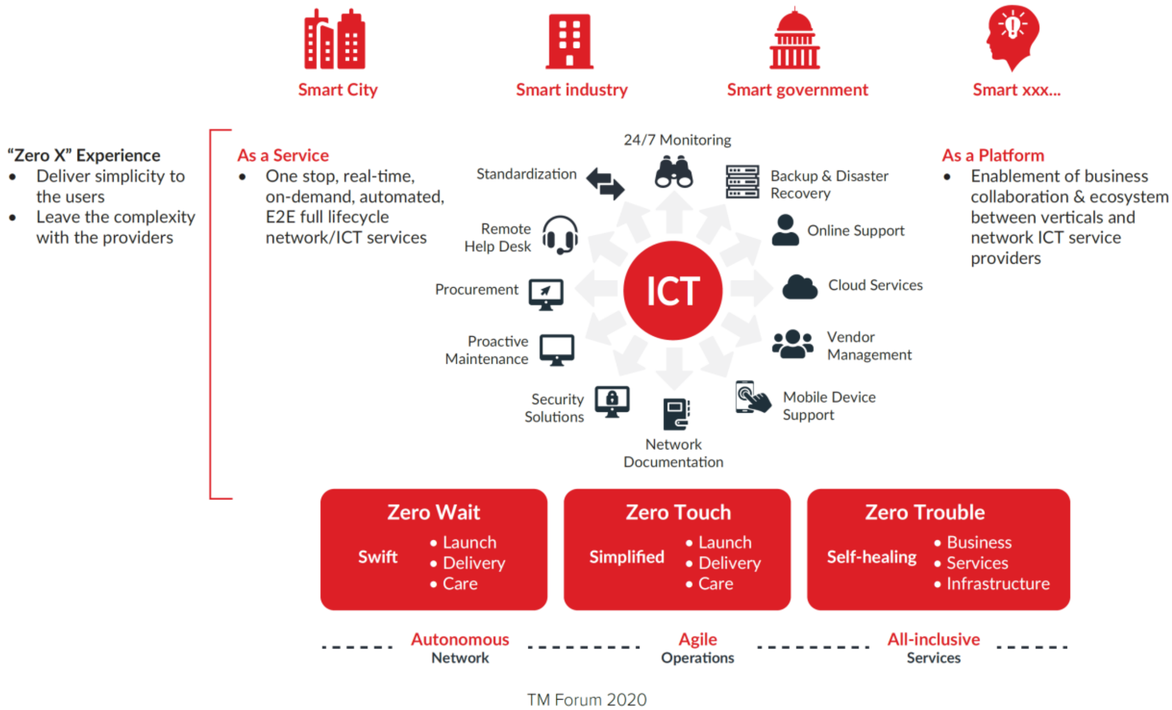

Figure 1. Autonomous Networks Vision (Source: TMForum, 2020)

AUTONOMOUS NETWORKS FRAMEWORK

The AN is also software architectural framework of autonomous, cross-orchestrated domains to implement this vision, Figure 2. The basic concept is to divide the network resources, be they physical or virtual, into domains that serve as autonomous but interconnected building blocks for the network, with the operations following those same boundaries. These are depicted as resource closed loop (four in the diagram).

With resources divided into the autonomous domains, there is a need for a coordination layer across the domains (3), the service operations closed loop, which ACG Research identifies as **cross-domain network orchestration**. Business operations are another layer above, with, again, closed loop operations (2). In ACG Research parlance, this is **cross domain business orchestration**. Topping it all off, self-directed networking defined as **business intent** connects the user to the entire stack to give a **user closed loop operation** (1).

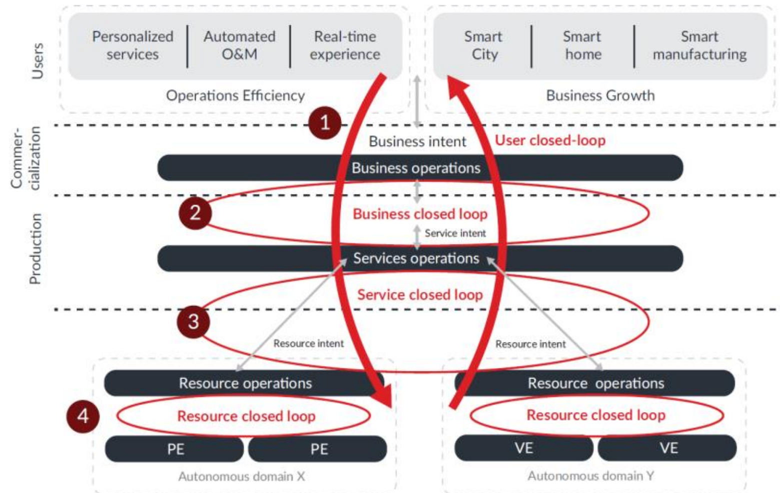

Figure 2. AN Framework (Source: TMForum, 2020)

The net effect is to have an overall closed-loop operation that extends from the top of the operations structure, through the business operations of the CSP, to the network resources, through the hierarchical layers, based on the concept of autonomous domain-based operations at the bottom of the stack using a philosophy of **single-domain autonomy, multidomains orchestration**.

Why Domain-Based Operations?

When the industry started its journey toward software-defined networking, there was speculation that the traditional hierarchical domain-based operations structures would be replaced with a much flatter structure. This has not been the case.[6] CSPs' networks are constructed of distributed, interconnected sets of elements, each performing its function in a technically distinct way, yet interworking with adjacent elements ultimately for a whole service to be delivered end to end. The distinct operation of a set of elements in this fabric constitutes a domain. For example, the radios in an operator's mobile network service constitute a distinct operational domain in those networks. Similarly, the IP/MPLS routers and Ethernet/MPLS switches performing backhaul transport for the traffic in those mobile network deployments constitute an adjacent and yet technologically different domain. As a final example, the relatively small nodes placed onto enterprise customer's premises to provide dynamically managed wide-area networking services in a software-defined WAN (SD-WAN) deployment create still another distinctly functioning set of nodes performing a unique set of functions in their own domain of operation for the CSP.

[6] There is an operations architectural concept being studied by ACG Research that we call management soup (reference: Mark H Mortensen and Teresa Monteiro, private communication). It posits a fully sliced network under SDN control, where fully sliced network resources are identified as being under the primary control of one of the SDN controllers with no controller hierarchy. The issue of resource contention in shared-fabric network infrastructures will have to be solved for this to be realized, however. We see this as a potential direction for autonomous networks of the future. The current AN domain-based operational paradigm is a necessary step that could usher in this more radical approach, introducing network automation and SDN control structures, which later melt into the soup as the autonomous domains are collapsed into fewer domains. One of my rules of thumb is that no technology is ready for implementation until it is well enough understood to allow one to glimpse that technology that will eventually replace it, as is the case with AN.

A domain represents a key focus area in automating operations. For the CSP to deliver its end-to-end offerings efficiently, it needs to rely on the continuously successful operation of each of its domains. Each domain requires people with specialized knowledge, using specialized tools, backed up by knowledge from the vendors of the infrastructure equipment and software in that area to provide excellent service. Clearly, if one domain is falling short of fulfilling its role, the service itself will be underperforming at least and potentially not be performing for the customer at all. For the sum of the parts (the end-to-end service) to succeed in delivering an enjoyable experience for the customer, each domain must be doing its part. ACG Research has determined that more than 80% of the automation of current network operations can be accomplished within the domains (through task, device, and domain automation), Figure 3.[7]

As the network and the network operations change, the domain structure also provides a good framework for evolution. By separating out the various network domains and providing separate domain controllers for each domain, they can evolve separately while making use of the expertise available from the network infrastructure vendors. As additional domains appear in the operations structure, their domain controllers can be added to the list and integrated into the overall operations by cross-domain orchestration systems.

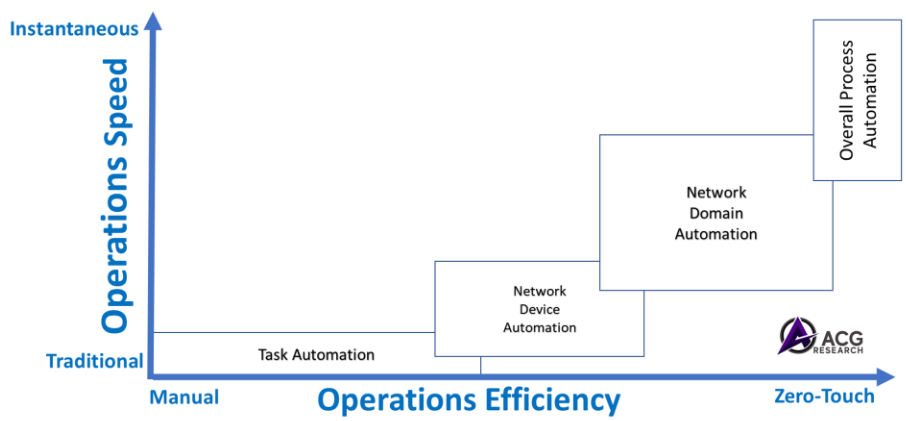

Figure 3. Operations Automation Potential at Each Hierarchy Level (Source: ACG Research, 2020)

What are the domains? ACG Research in its Domain Control and Orchestration syndicated research program[8] has identified the primary domains that represent a good view of the range of domains currently being implemented in CSPs, Figure 4.

[7] See, Mortensen, Mark H, "Economic Benefits of Network Automation." ACG Research, 2020. https://www.acgcc.com/blogs/2020/04/23/capitalizing-economic-benefits-network-automation/.

[8] See https://www.acgcc.com/blogs/2020/03/28/domain-control-and-orchestration-future-automated-network/.

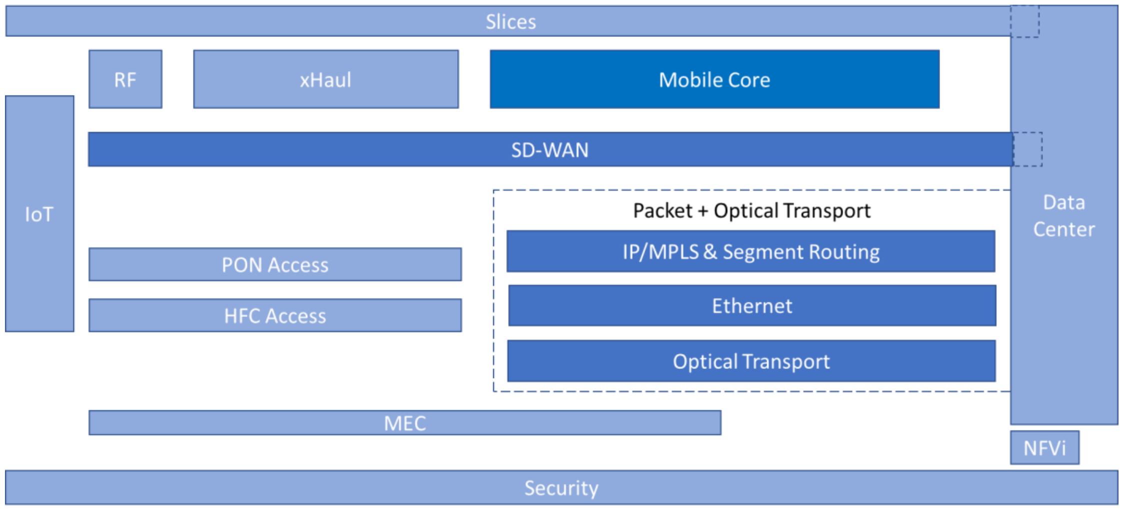

Figure 4. Domain Overview (Source: ACG Research, 2020)

Individual domains are identified with cross-domain orchestration done across the various domains to plan, deploy, and manage those network and service functions that transcend a single domain. As the domain management becomes more autonomous and the cross-domain orchestration functions deepen, ACG Research expects that the domains will simplify into fewer domains. We already see this happening in the packet and optical area, as shown in the diagram. Some vendors are providing a set of interacting domain and control and cross-orchestration functions as microservices that can be delivered to manage the domains separately or configured as a single multifunction system for managing the optical, ethernet, and IP/MPLS domains as a single entity, effectively collapsing the domains into a single management domain.

> The telecoms industry has been waiting for autonomous networks, but there have been major challenges that have gotten in the way in the past.

WHY NOW?

In the late 1980s, many of us in the industry looked toward the new millennium and worked to envision what 21st century operations of a CSP could look like. In my case, I lead a team of distinguished members of technical staff at Bell Laboratories from the switching, transmission, and operations software organizations. We were given one year to reimaging network operations and automation from the ground up. We came up with the 3 Selves of Self-Provisioning, Self-Healing, and Self-Optimizing that even in 2020 are still key to the modern AN network vision, along with an implementation plan for a series of what are now called domain controllers. We laid out this plan in what we called the Service-Net 2000 vision. Although that vision was useful in guiding the cross-organizational work for many years, and there were pockets of success, we found during the next 10 years that our technology was simply not up to the task of achieving the full vision. Looking back on it, I realize that there were several fundamental issues, which now can be tackled, as articulated in Table 1.

Issue	AN Blocker	Solution Today
Tangled control hierarchy.	Domains had to expose all their information to higher layers for provisioning since services were offered at all levels of connectivity (for example, dark fibers in a bundle, timeslots in a TDM transport system, capacity in a packet system).	Network slicing architecture that assigns control of portions of shared network resources to different domain controllers.
Limited computing power in the network elements.	Limited the self-discovery and reporting of the status and state changes of network elements to domain controllers.	Inexpensive, ubiquitous computing in the network elements, both embedded and in disaggregated software control modules.
Need for drill-down from overall service-level assurance systems.	Requires transparent access to current NE state or transmission and storage of large near-real-time data northbound.	Data lakes and big data technologies that can store and quickly analyze vast amounts of data.
Large amounts of near-real-time data need to be transported northbound for provisioning and surveillance.	Data transport of the large volumes of data was too expensive to implement for internal operations, also used too much computing power in the network elements.	Less expensive, large data pipes for internal operations data movement, less expensive computing power in the network elements.
Difficult to characterize and control network elements because of command line NE interfaces and proprietary interfaces northbound and southbound from EMS/NMS systems.	EMS/NMS systems came from the network element vendors[9], controlling highly proprietary features in the NEs. Also, command-line interfaces only for many packet systems.	YANG models and NETCONF APIs; network element interfaces that expose the full range of feature functionality; SDN controllers with intent-based northbound interfaces.
Fast evolution of the network elements meant that the EMS/NMS/OSS system synchronization was very	This slowed down deployment of multivendor control software northbound of the network elements or EMS/NMS systems.	Cloud-native architecture, together with DevOps processes and CI/CD implementation can deliver software changes much

[9] Attempts like MTOSI from the TMForum to standardize the northbound interfaces from EMS/NMS systems met with only limited success. See https://www.tmforum.org/mtosi/.

difficult.		more rapidly and efficiently.
The large data volumes that need to be evaluated, correlated, and turned into manageable information are exceeding human capabilities.	The single pane of glass management concept was particularly useful, but the network complexity has overtaken that technology. AI systems were capable but too hard to train.	Artificial intelligence technology is becoming mainstream for operations, while machine learning has made the AI systems operationally viable.

Table 1: Past Issues in AN Implementation and Status (Source: ACG Research, 2020)

The time is now to push toward autonomous networks. The CSPs need them, the market demands, them, and the technology is now ready to step up.

The CSPs Need the AN

- CSPs recognize that they need to compete more effectively with web-scalers and others who can and are offering network-as-a-service as parts of other offerings in the consumer, enterprise, and government markets.
- The rise of effective industry forums for management systems and disaggregated network elements has started to standardize APIs, spurred on by CSPs who recognize that they are in an existential fight.
- AN provides the best chance of CSPs transitioning to become digital service providers, allowing flexibility for the existing CSPs to pick their individual transformation paths.
- AN offers a framework that can help smooth the required organizational changes via a set of step-changes to fully autonomous operations.

The Market Demands AN

The enterprise and consumer markets are demanding greater satisfaction even as their needs grow for faster, more reliable, less expensive service with a greater degree of control over their own services.

The Technology Can Meet the Needs of AN

- Distributed, inexpensive computing power is now available for network elements, controllers, and the northbound software systems. This allows computationally inefficient but agile and extensible software programming techniques and architectures to be used ubiquitously.
- Large data pipes are cost-effective for moving large amounts of management data, allowing for distributed multicloud computing to be brought to bear.
- Database and analytics technology have matured to be able to handle, cost-effectively, incredibly large volumes of data.
- Software technology has matured to the point of being able to adapt quickly to changes in the network elements or other software systems via service-oriented APIs, intent-based interfaces, cloud-native architectures, DevOps development processes, and CI/CD deployment methodologies.

- AI control technology has been extended to machine learning that when trained with the large data sets available from centralized cloud-based data lakes provides fast, inexpensive implementation possibilities.
- The move to virtualize and containerize the functions (or at least the control) of most network elements provides an exceptional opportunity to update the evolution of the management control as well as speeds up its evolution to software-time (instead of hardware-time).
- The concept of slicing a shared fabric communications network to provide specialized needs for different services or different customers untangles the hierarchy and provides a much more fluid control structure for network management.
- The move toward 5G networking for both mobile and fixed networks provides a technological breakpoint that can be exploited for modernization of the network and its management structure.

CHALLENGES

There are still some major challenges to be overcome to fully implement the vision of autonomous networks, but there are a approaches that are already on the horizon to meet them as network autonomy progresses from the current levels to full Level 5.

Mixture of Legacy Physical Elements and New Physical and Virtual Elements

Much of the network is not still legacy equipment, not virtualized, which gives it the quick-response elasticity, nor software controlled to give it configuration agility. This means that some parts of the nonvirtualized part of the network will be left behind or will have be adapted to the new AN structure through northbound interfaces to its current EMS/NMS systems. Some network elements will have thin adapters added.

Trusting Closed-Loop Operations

Although much automation has been implemented using simple robotic process automation[10] macros, many CSPs are loath to allow software systems to implement any large-scale changes in their network without human supervision, adding additional cost and delay[11]. A combination of things is needed to solve this problem:

- Time for the operations managers to become comfortable with the AI automation software, as it proves itself.
- Explanation facilities from the automation software for explaining to humans why a conclusion was reached by an AI agent[12].
- Simulation capabilities to show what the effect of major changes on the network and service KPIs.

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[10] See, for example, https://www.uipath.com/rpa/robotic-process-automation.

[11] See https://www.acgcc.com/blogs/2020/01/28/five-barrier-questions-to-ai-adoption/ for a more detailed explanation of the key management issues involved in implementing closed loop operations.

[12] See, for example, the DARPA XAI project, https://www.darpa.mil/program/explainable-artificial-intelligence.

- Operational sliders that give the responsible managers the ability to control how open loop or closed loop the AI works.
- AI governance structures that detect that a proposed action would lead to undesirable consequences in a domain or in a cross-domain service (particularly when multiple AIs are all attempting to optimize the system, based on their individual goals).
- Infrastructure for AIs to share best current practices and applicable machine learning (AI academies) and a methodology for scoring and perhaps even certifying the training datasets.
- AI training and retraining regimens, when needed.

Integration of Communications with Computing and Storage

As the physical network becomes more virtualized and additional services are added through software, it becomes more intertwined with the computing and storage in data centers. As computing power is added to the edge, the computing and storage become more intertwined with the network. This can lead to another tangled hierarchy that needs to be addressed. Integrated control structures for service chaining across communications, computing, and storage will evolve to meet this need.

Integration among CSPs

CSPs do not exist in a vacuum. Because most CSPs work within defined geographical boundaries, enterprise services often need to transcend these boundaries, involving multiple CSPs. Closed-loop operations involving these entities will be difficult technically but even harder to negotiate and manage from a business perspective. The needs of large enterprises will, inevitably, drive this trend, with direct interfaces among CPS and the use of cross CSP exchanges.

Integration with Trading Partners, Suppliers, and Resellers

As with the inter CSP problem, there are the operations that go across CSPs' suppliers and resellers. Significant progress is being made in this area, with offer catalogs being automatically traded and updated in e-commerce systems. Web-scalers already have such standard and *de facto* interfaces available for enterprises to use in specifying, ordering, and monitoring computing resources. These will be extended to include the communications components.

SD-WAN Operations Integration

SD-WANs are currently often under the control of specific controllers, violating the domain control hierarchy and providing single panes of glass for management. These will be replaced by autonomous domain controllers over time, with northbound interfaces to SD-WAN cross-domain orchestrators.

Slicing Architecture

The operations architecture for a highly sliced network is not yet understood. Several vendors have created slicing managers that directly work with network resources, others work through the domain controllers. This will take some time to sort out.

Overall Network Inventory Architectures

The issue of whether inventory should exist at a domain level (and what information should be made available to the higher levels) or at an overall network level or both is still to be addressed. Several approaches with advanced federation capabilities to allow flexible architectures are available already in the marketplace.

Integration with NFV Computing and Storage Infrastructure Control

In some architectures, especially from virtual network infrastructure vendors, the management of the computing storage infrastructure is integrated into the domain operations. In many other operations architectures[13] it is a separate domain, not under the control of the domain controller. In such cases, however, the domain controller could initiate the allocation and implementation of the VNFs/CNFs via messaging to the infrastructure controller when additional infrastructure resources are required. ACG Research believes these standards will evolve to include this feature.

Network Service Assurance Architecture

To fully do closed-loop operations on a domain level, the domain controller needs access to the current state of the network domain, basically incorporating all the service assurance functions. In most CSP operations, a centralized whole-network service assurance system is implemented to support the domain, cross-domain, and end-to-end service assurance functions. How to architect the information gathering, processing, and control structure is an item still to be addressed. Several possibilities exist, including the full sharing of information using data lakes or the disaggregation of the centralized service assurance systems into individual domains with a federation of the information via a hierarchy of federated service assurance functions.

Need for Close Industry Collaboration

Meeting all these challenges will require the collective work of CSPs, network infrastructure vendors, independent software vendors, and systems integrators. Fortunately, several industry forums have shown themselves to be effective means for collaboration on visions, generic requirements, and interoperability testing. Although inter-forum cooperation is increasing, aligning the efforts, much more is needed.

CONCLUSION

The time is now to adopt the goals of the 10xNetwork, the domain-based management architecture and evolutionary path of autonomous networks, and the vision of the communications networks of the future, enabling components of an intelligent composable fabric for creating digital operations platforms for the CSPs themselves and for their enterprise customers. The autonomous network is an essential piece of this evolution.

[13] For example, the Broadband forum Cloud-CO in TR-384 (see https://www.broadband-forum.org/download/TR-384.pdf) and ETSI Open Source MANO (OSM) https://www.etsi.org/technologies/open-source-mano.

About the Author

Dr. Mark H Mortensen (mmortensen@acgcc.com, @DrMarkHM) is an acknowledged industry expert in communications software for the TMT sector, with over 40 years of experience in OSS and BSS specifications, software architecture, product marketing, and sales enablement. His work has spanned the gamut of technical work at Bell Labs, strategic product evolution at Telcordia, CMO positions at several software vendors, and as a research director at Analysys Mason. Most recently, Mark has focused on the technology and processes of digital transformation for Communications Service Providers and the growing automation and orchestration of network and business processes. He joined ACG Research in 2018 where he is responsible for Communications Software research and consulting. He recently, with his colleague, Paul (PJ) Parker-Johnson launched a new syndicated research program, *Domain Control and Orchestration,* that characterizes the state of the industry, profiles vendor solutions, and tackles many of the issues described in this paper.

ACG Research delivers information and communication technology market share/forecast reports, consulting services, and business case analysis services.