Private 4G/5G Connected Edge Platform for Enterprises

Executive Summary

Aether™ is ONF's new 5G Connected Edge platform. Aether provides mobile connectivity and edge cloud services for distributed enterprise networks, all provisioned and securely managed from a centralized cloud. Based on open source components and optimized for cloud deployments, it is easy to deploy, highly scalable and designed for rapid new service onboarding in a multi-cloud environment. Aether is a highly flexible system that empowers cloud providers, network operators, equipment vendors, system integrators, IoT solution providers and new market entrants to deliver new innovative services to enterprises embarking on digital transformation projects.

Introduction

Enterprises have an increasing appetite for private 5G/LTE services. It has been reported that over two-thirds of industrial companies from a wide range of business verticals want such services within two years[1]. This desire is driven by a number of motivations:

- Enterprises see mobile connectivity as one of the critical enablers for their ongoing digital transformation, which strives to achieve real-time automation of processes, machinery and manufacturing via analytics, video surveillance, remote control, real-time operational monitoring, and predictive and preventative maintenance.
- Today's Wi-Fi networks are insufficient for handling the needs of the IoT-enabled digital transformation due to the lack of reliability, capacity and security. Mobile networks are superior in all these dimensions, but historically they have been expensive, complicated, and out of reach to enterprises who want to operate their own networks.
- Wireless connectivity needs to be reliable, secure, predictable and delivered with low latency - especially for mission-critical applications. With use of sensors and IoT growing at monumental rates, the network also needs to support large numbers of devices and a broad variety of device types. And it is essential that performance is not compromised as the network scales.
- Enterprises want full control of their own data - controlling who can access it and where it lives and migrates. This creates a need for programmatic traffic localization and subscriber connectivity service-graph construction and management.
- Enterprises need to be able to deploy edge services from public cloud providers. AWS, Azure and Google Cloud are all enabling the execution of latency sensitive functions in cloudlets onsite at the enterprise. Enterprises need a single platform that can seamlessly support deployment of edge services from any and all cloud providers.

Designing, deploying, and maintaining mobile networks have traditionally been expensive and complex, minimizing the wide-spread deployment of private mobile networks. The private enterprise networks of today need to be reasonably priced, easy to deploy, seamless to scale, adaptable for supporting new edge services, and simple to manage with enterprise-control of subscriber management, traffic steering, service-graph construction, etc. Additionally, to match how enterprises consume other services today, any mobile edge cloud solution should be cloud-based and deployed as a managed service.

[1] Capgemini Research Institute, "5G in Industrial Operations: How Telcos and Industrial Companies Stand to Benefit," Report, May 29, 2019.

The technology pillars of disaggregation, virtualization, SDN'ization, and cloudification that are fueling the transformation towards 5G provide the foundation for addressing these issues. One additional enabler for private enterprise networks is the advent of new types of available spectrum for such networks, namely, the CBRS-band in the US and dedicated licensed bands for enterprise use in Germany, and soon also in the UK, Sweden, Hong Kong and Australia, with more countries to follow. The availability of unlicensed, lightly-licensed and enterprise-licensed bands that are free or inexpensive will undoubtedly play a big role enabling widespread deployment of private mobile networks. This will be a boon for enterprises, and also represents a new and compelling business opportunity for operators, suppliers and for new market entrants.

Aether System

At ONF, building on our well-established, operator-approved and deployed platforms, we have developed Aether, a cloud-enabled private mobile network system for enterprises. Aether flexibly leverages all available spectrum bands, including both operators' licensed bands and the CBRS-band. Aether is an open source enterprise platform for leveraging private cellular connectivity and mobile edge computing (MEC) for mission critical applications and operational use cases. Aether runs on open-spec commodity compute and networking hardware and connects with 3GPP compliant small-cells for cellular access as shown in Figure 1. Designed to be delivered as a cloud managed service, Aether offers a harmonious substrate consisting of a number of enterprise services, including private cellular connectivity, connected edge cloud and fine-grained traffic visibility and control services. Rich northbound and southbound APIs allow the platform to host the enterprise operational platforms and applications, connect them to data sources and collect rich telemetry from the connected end-points, and the data they exchange.

Aether's *Private 4G/5G Connectivity Service* provides cellular connectivity to enterprises, empowering them with a solution that provides them with the level of security scaling, and sustained Quality-of-Service (QoS) provisioning that today only mobile network operators enjoy, while simplifying the deployment, operation and lifecycle management by means of a managed service. The connectivity service is realized leveraging an on-premises local break-out, which brings in programmatic Internet and Intranet access and QoS tiers, and network slices, including those for high-bandwidth, low latency, mission critical connections.

Aether's *Fine-Grained Traffic Visibility and Control Service* provides enterprises with a programmatic means of per-packet visibility of select flows, allowing for enhanced security guarantees, assurances on intended operation and QoS policy enforcements.

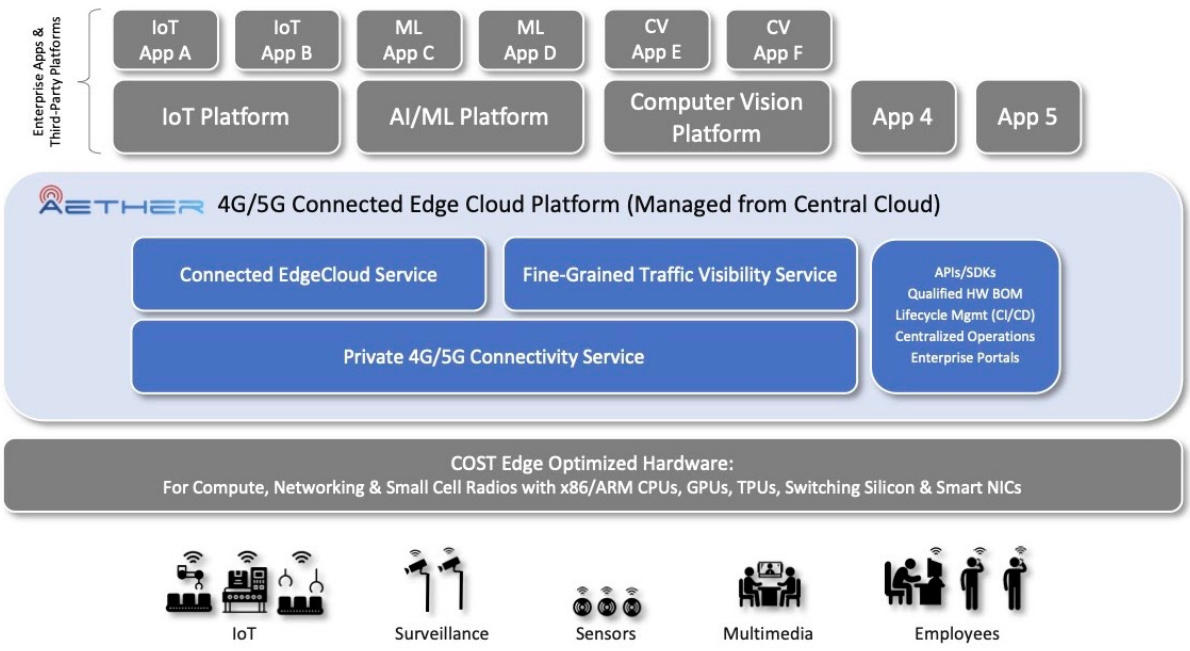

Figure 1: Aether Managed Services

Aether's *Connected EdgeCloud Service* provides enterprises programmatic means to dedicate connected compute, storage and networking resources at the edge for a select set of third-party platforms and applications that they wish to host on promises. The connected nature of the EdgeCloud service allows for, as an integral part of the service, simple programmatic connectivity between these platforms and applications and the cellular end user and IoT devices as well as connectivity between them and the Internet and central clouds.

Starting in November 2019, the Aether community has been rapidly architecting, developing, piloting and testing Aether over multiple sites. We have been using the CBRS band for ease of deployment. We call both the system and our pilot deployment Aether (pronounced 'ether').

Consider an enterprise with employees, visitors, IoT devices, meeting rooms with multimedia communications, surveillance cameras as well as sensors aiding the process and manufacturing automation as illustrated in Figure 2. Aether deployment adds an Aether Connected Edge (ACE) as well as a number of small cells into the Aether enterprise edge site. The Aether Connected Edge hosts all connectivity network functions, including all virtualized RAN components, as well as the mobile core user plane. The presence of this user plane at the enterprise edge allows for local traffic breakouts. ACE also hosts enterprise-approved applications that benefit from a local point-of-presence. Aether

Connectivity Control (ACC) provides a common cloud-hosted multi-tenant 5G and LTE core for delivering Connectivity-as-a-Service. An Aether Management Platform (AMP) runs in the central cloud and oversees, as a managed service, operational control, lifecycle management, monitoring, and multi-cloud connectivity for the Aether Connected Edge. Further, it allows, via the Enterprise Control Portal, each enterprise to easily control and manage its network subscribers, its network slices and quality-of-service profiles, and its traffic localization policies.

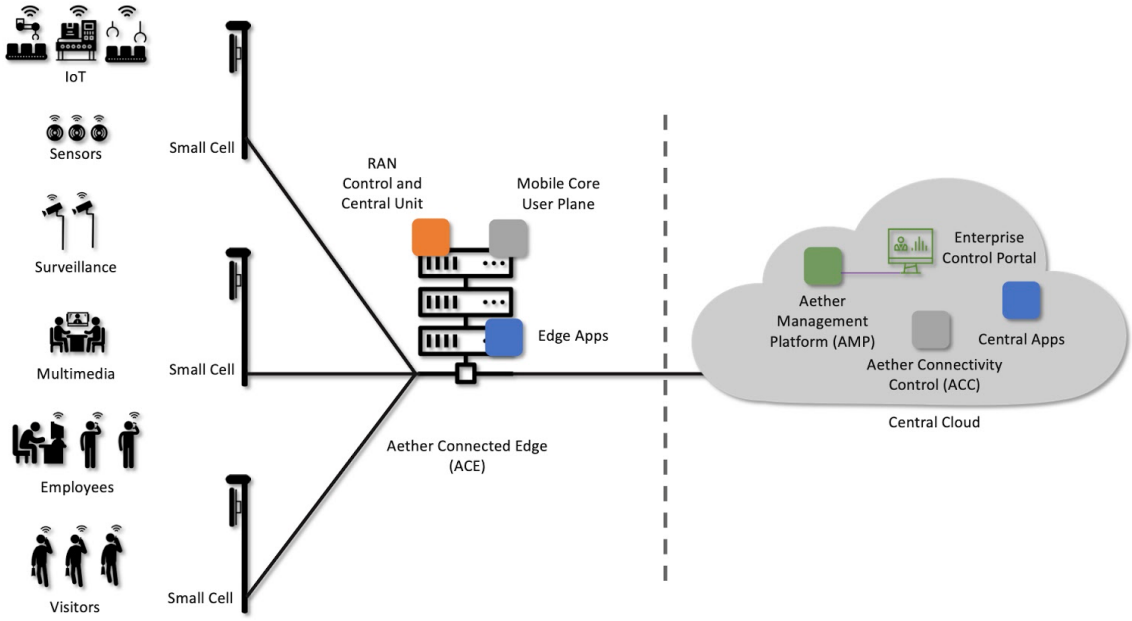

Figure 2: Aether providing Enterprise-5G/LTE-Edge-Cloud-as-a-Service

Aether has been architected with highly flexible modularity in mind, enabling different business models. One can think of a variety of models by answering the following three fundamental questions: Who will own the infrastructure and the spectrum? Who will operate the network? Who will manage the edge cloud? For example, operators may provide 5G/LTE and edge cloud services to enterprises by leveraging their own licensed band spectrum, and running Aether Management Platform (AMP) and Aether Connectivity Control (ACC) from their Telco Public Clouds. Operators may alternatively use the CBRS-band to offer these services. They may also partner with public cloud providers to host some or all of the Aether public cloud components from the public cloud. In all of these cases, operators would operate the network. While they may also manage the Aether Connected Edge (ACE) sites, they may also partner with public cloud providers for this purpose.

Alternatively, some of the enterprises may choose to own their own networks, by purchasing their own infrastructure and running their networks using the CBRS band, or one of the upcoming enterprise specific licensed bands. They may decide to operate the network themselves, or outsource this to an operator, a vendor, or a systems integrator. While some enterprises may want to run the AMP and the ACC on a public cloud, some others may choose to run them out of one of their own data centers.

Clearly, there are other possible business models as well. Aether, with its modular architecture allowing its centralized Management Platform, and Connectivity-as-a-Service solution to run together, or separately from *any* central cloud location that enables Kubernetes environments, and its flexible use of operational spectrum for 5G/LTE services, empowers all of these business models.

Aether Architecture

As illustrated in Figure 3, Aether architecture is comprised of the following components:

- Aether Connected Edge (ACE): A Kubernetes-based micro-datacenter running on-premises, hosting a combination of the Aether Connectivity Service (ACS) and optionally one or more third-party edge platforms/applications selected by the enterprise. Each ACE cluster is composed of compute, network fabric and small cells (CBRS for our pilot network) to provide coverage and end-user device density. Depending on the enterprise size and target workload, an ACE cluster may be as small as a single switch and server, or as large as 3 or 4 full racks.
- SDN Substrate: Each ACE cluster is built on an SDN-based switching fabric constructed from P4-programmable white-box switches. The switches are arranged in a leaf-spine topology and controlled by ONF's ONOS® network operating system. The fabric data plane is instrumented to support Inband-Network Telemetry (INT), collecting fine-grain data. P4 is also used to implement the mobile core's User Plane Function (UPF) on-switch, as part of the fabric data plane. The use of P4 and INT in its data plane is the cornerstone of Aether's support of the DARPA-funded Pronto project, which has the goal of providing verifiable closed-loop control (see below).
- Aether Connectivity Service (ACS): An edge-hosted 5G/LTE connectivity service, including support for local break-out. ACS consists of the virtualized central units (CU) of the small cells, an O-RAN compliant near real-time RAN Intelligent Controller (nRT-RIC) based on ONF's SD-RAN[2], and ONF's P4-based dual core (LTE and 5G)

[2] O. Sunay, et. al. SD-RAN: ONF's Software-Defined RAN Platform Consistent with the O-RAN Architecture, ONF White Paper, August 2020.

User Plane Function (UPF). ACS runs on-premises, as a tenant of ACE, and is paired with an instance of ACC running in the central cloud.

- Aether Connectivity Control (ACC): An open source, 3GPP-compliant Mobile Core *control plane* built around OMEC™ (EPC) and Free5GC (NG-Core). ACC runs on the central cloud (Google Cloud for our pilot network), where the corresponding User Plane Function (UPF) runs on-premises, as part of ACE. ACC supports multiple instantiations of the control plane running on behalf of different enterprises and different network slices associated with a given enterprise.
- Aether Management Platform (AMP): A highly available cloud service used to control, configure, monitor, and lifecycle-manage both (i) multiple ACE clusters at edge locations, and (ii) multiple control planes running as part of ACC. AMP defines Aether-specific workflows for adding and controlling subscribers, small cells, mobile core user planes, and 3rd-party edge services; a global infrastructure for collecting monitoring and logging data about Aether sites and services; operator alerts and diagnostic tools for analyzing the collected data; and a CI/CD toolchain for managing the lifecycle of the deployed systems. AMP itself is cloud agnostic, and as such, can run on commodity clouds (e.g., Google Cloud, AWS, Azure), operator-own Telco clouds, (e.g, AT&T's AIC), or an enterprise's own data center. For the ONF pilot deployment, the AMP runs in the Google Cloud.

Aether Enables Pronto

Aether serves as the underlying platform for Pronto, a DARPA-funded project to implement and deploy a full-featured network—including 5G—under *verifiable closed loop control*. Pronto is a joint research effort of Stanford, Cornell, Princeton and ONF to build a more secure and robust Internet, with the goal of serving as an exemplar for others in industry, education, and government to replicate.[3]

Pronto builds on Aether by extending the SDN Substrate and SD-RAN with fine-grain network telemetry, formal verification, and closed-loop control. Figure 4 expands on the *Verifiable Closed-Loop Control* element shown in Figure 3. Pronto's approach is to instrument the switching fabric with INT extensions, feed the collected fine-grain measurements into a verifier, and close the loop back to the ONOS-based control plane when corrective action is required.

[3] N. Foster, et. al. Using Deep Programmability to Put Network Owners in Control. ACM SIGCOMM Computer Communication Review, October 2020.

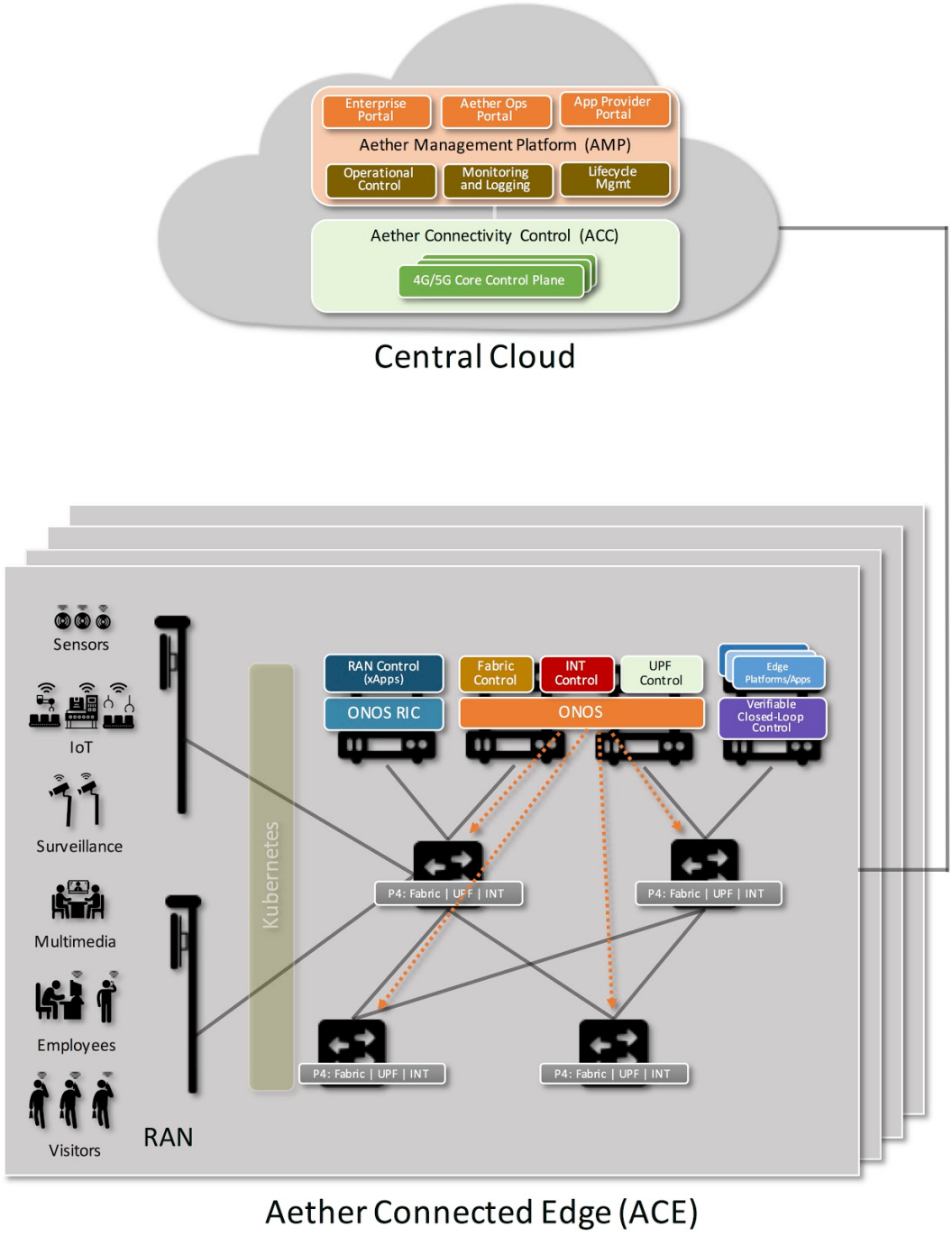

Figure 3: Aether Architecture

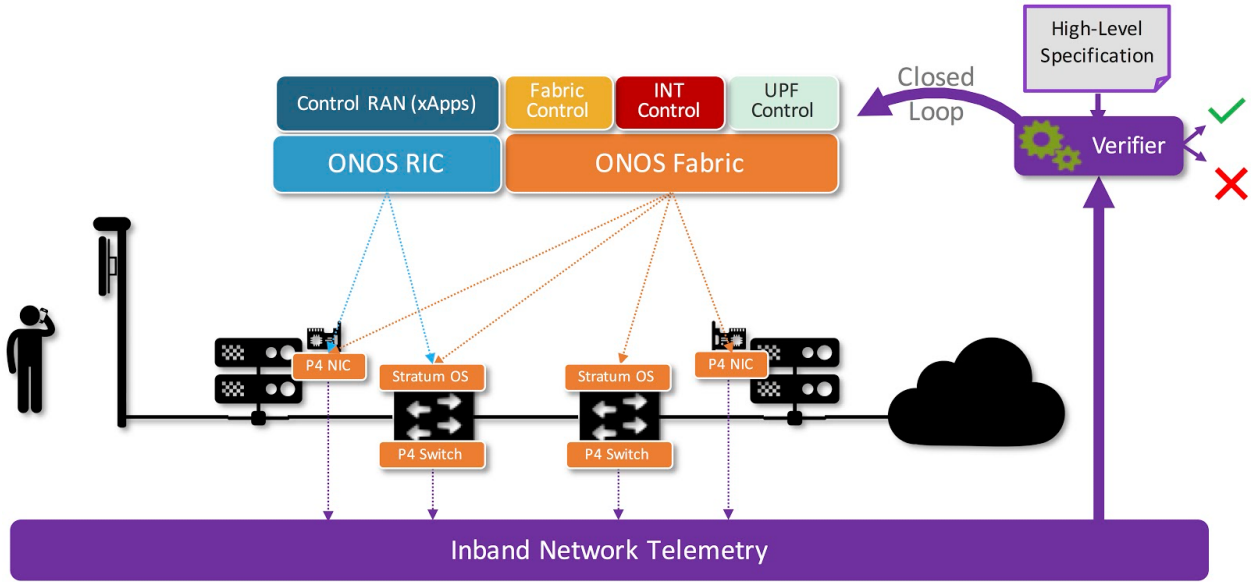

Figure 4: Pronto supporting verifiable closed-loop control

Stakeholders and Interfaces

A critically important aspect of any operational cloud platform is the set of interfaces it exports, and the stakeholders they serve. In Aether, this includes the following:

- AMP provides a high-level portal for each enterprise to monitor and control their local edge connectivity. This includes the ability to add and control devices and subscribers, and assign them to network slices.
- ACE supports a platform-level API for enterprises or their service providers to deploy and manage edge applications on ACE. This includes the ability to support third-party IoT applications and platforms.
- Aether's SDN Substrate includes an SDK for developers to introduce new features into the programmable network infrastructure. This includes new control plane applications (including RAN xApps) and new data plane functions.

In addition to its external-facing APIs and portals, AMP also provides a full complement of provisioning and lifecycle management tools. The Aether DevOps team at ONF uses these open source tools to Continuously Integrate (CI) and Continuously Deploy (CD) software on the live operational Aether network. Changes are developed and tested in a staging network, and then automatically pushed to the multi-cloud production network. Based on best practices in DevOps, this toolset, illustrated in Figure 5, dynamically delivers bug fixes,

regression and operational testing, hardening, scaling, and new features with minimal service disruption and without requiring end-user intervention.

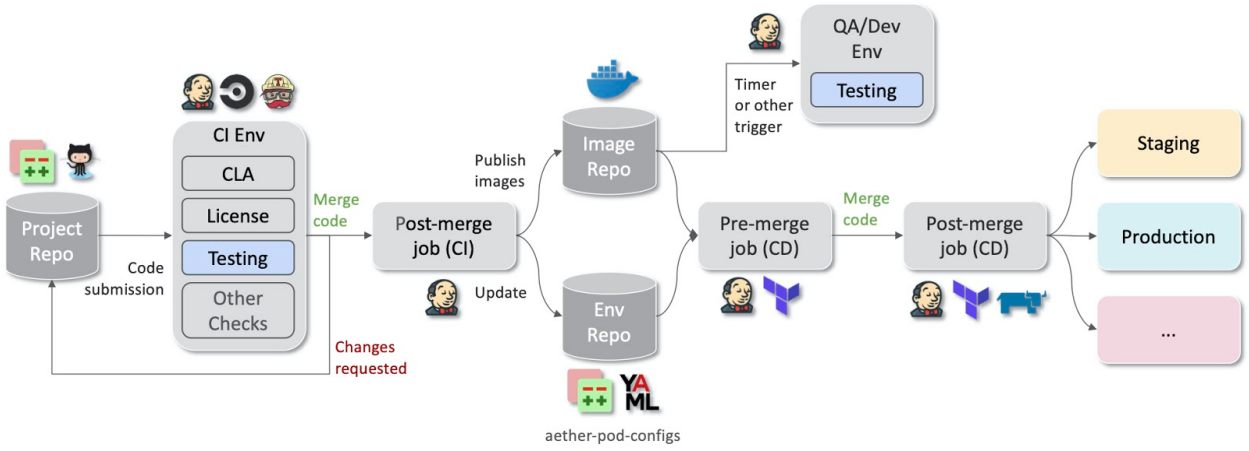

Figure 5: Aether CI/CD Pipeline

Aether Pilot Deployment

Aether has been operational as a Pilot Network since December 2019. The first ACE has been at ONF's Menlo Park office, with the ACC and AMP running in a highly-available manner from Google Cloud's US West server farm. We have successfully connected Google Pixels, iPhones, CBRS dongles, and IP cameras connected with CBRS-enabled video bridges to our cloud managed CBRS network, and operation has been stable. Parallel to the pilot production network, we have also set up a staging cluster for CI/CD operations, leveraging a commercial RAN emulator from ng4T.

Since then, we rapidly expanded the network with more ACEs around the globe. As illustrated in Figure 6, we now have ACEs at ONF's Tucson office, Intel Labs in Hillsboro, AT&T's 5G Lab in Atlanta, NTT office in Osaka, Japan, Telefonica in Madrid, Spain, and Ciena's 5G Lab in Montreal, Canada. And as part of Pronto, ACE deployments are already underway at Stanford, Princeton, and Cornell.

Aether has already gained significant interest in the industry. Consequently, additional ACEs deployments are in various stages of development at various companies and institutions around the globe.

Figure 6: Aether Pilot Deployment

Aether's Relationship to Other ONF Projects

There are several on-going, interrelated projects at ONF, and Aether both builds on and helps advance this work.

Aether's ACE and AMP are built on the CORD® platform. ACE leverages ONOS and Kubernetes in its platform. AMP leverages aspects of CORD's and ONOS' operationalization toolchains. Aether effectively disaggregates CORD, moving some of its functionality to the public cloud, and adding other components on the path towards offering a managed service.

Aether is iteratively incorporating SD-RAN[4] as it matures. The ONF work developing an O-RAN compliant RAN solution with an ONOS-based Radio Intelligent Controller (RIC) is being integrated into Aether's ACS on ACE.

Aether builds on OMEC for 4G and Free5GC for 5G, and creates a multi-service multi-tenant mobile core distributed between ACS on ACE and ACC. Specifically, Aether distributes the mobile core user plane to the edge cloud and centralizes the mobile control plane in the public cloud, providing the capability for the control plane to oversee the control of many user planes at different edge locations.

[4] ONF SD-RAN Web Page: https://opennetworking.org/sd-ran/

Aether's SDN fabric for ACE leverages not just ONOS, but also other ONF projects, including: (1) P4 data plane programmability, (2) the Stratum Switch OS running on each switch, and (3) the Trellis leaf-spine fabric control application.

Last, but not least, Aether is serving as the foundational platform for COMAC which strives to enable convergence for multiple access technologies including mobile and broadband. The connectivity network functions, for both user plane and control plane, will be hosted on Aether to extend its current managed connectivity offering towards a managed *converged* connectivity offering.

Conclusion

It is clear that the 5G community needs to accelerate the enablement of 5G/LTE services for enterprises. This will catalyze enterprises' on-going digital transformation and also will enable operators to provide these services much sooner. In this context, we believe Aether presents a big opportunity. We invite organizations to actively participate, collaborate and adopt this exciting new endeavour. ONF will help aligned organizations deploy an ACE site, join the pilot network, develop new, innovative applications for enterprises on Aether, and build commercial offerings based on the Aether platform.

About ONF

The Open Networking Foundation (ONF) is an operator led consortium spearheading disruptive network transformation. Now the recognized leader for open source solutions for operators, the ONF first launched in 2011 as the standard bearer for Software Defined Networking (SDN). Led by its operator partners AT&T, China Unicom, Comcast, Deutsche Telekom, Google, NTT Group and Turk Telekom, the ONF is driving vast transformation across the operator space. For further information visit http://www.opennetworking.org