



Executive Summary

Aether™ is ONF's new Enterprise-5G/LTE-Edge-Cloud-as-a-Service system. Aether provides mobile connectivity and edge cloud services for distributed enterprise networks, all provisioned and 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 various business models around private 5G/LTE enterprise networks that may involve, in addition to enterprises, one or more of the following: network operators, public cloud operators, vendors, system integrators and new market entrants.

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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 years¹. This desire is due to a number of reasons:

- 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 as the network scales, it is essential that performance is not compromised.
- Enterprises want full control of their own data - controlling who can access it and where it lives and migrates. These requirements lead to the 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 for 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,

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

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.

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 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 operators' and enterprises' licensed bands as well as the CBRS-band. Aether creates an Enterprise-5G/LTE-Edge-Cloud-as-a-Service, enabling simple and seamless deployment of mobile connectivity as well as enterprise edge cloud capabilities that are both centrally orchestrated from the public cloud. Aether makes it possible for enterprises to deploy mobility and edge services across a multi-site footprint as an elastic and scalable cloud service.

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 1. Aether deployment adds an Aether Edge as well as a number of small cells into the Aether enterprise edge site. The Aether Edge hosts all connectivity network functions, including the mobile core user plane, to allow for local traffic breakouts. It also hosts enterprise-approved applications that need local

presence. The control plane of the mobile core runs from a central cloud², providing Connectivity-as-a-Service. An Aether Control and Management Platform runs in the central cloud and oversees, as a managed service, lifecycle management, monitoring, and multi-cloud connectivity for the Aether Edge. Further, it allows, via the Enterprise Control Portal, the enterprise to easily control and manage its network subscribers, its network slice profiles as well as its traffic localization policies.

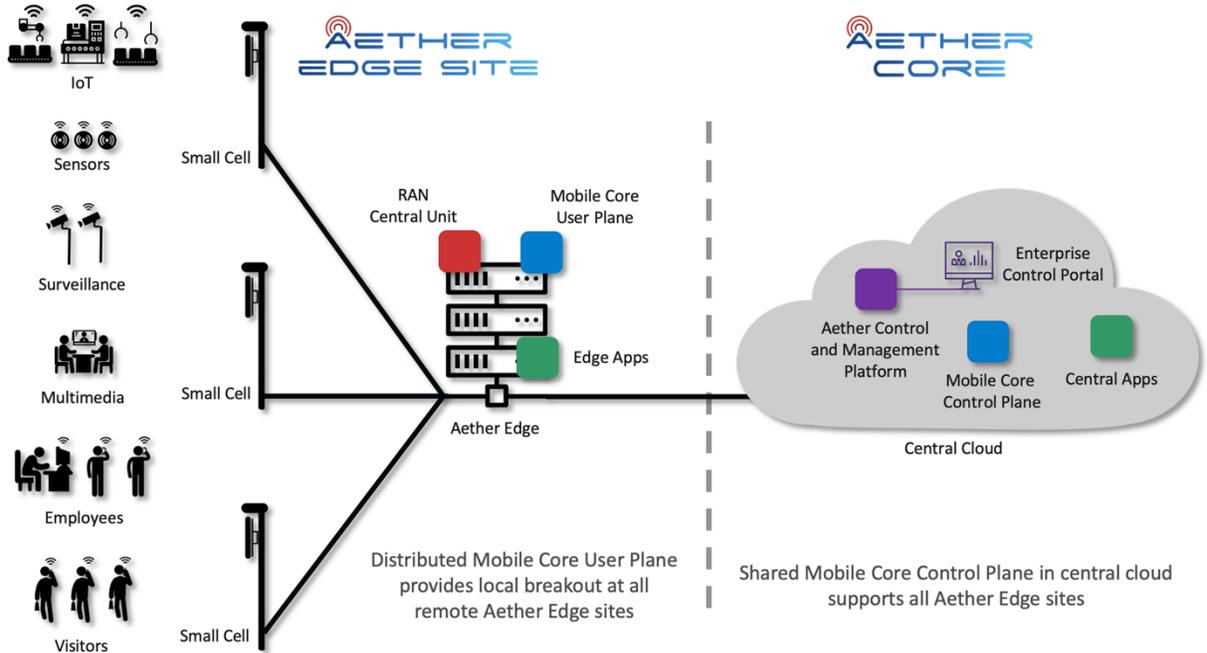


Figure 1: Aether providing Enterprise-5G/LTE-Edge-as-a-Service

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 the Aether Control and Management Platform and the mobile core control plane from their Telco Central Clouds. Operators may alternatively use the CBRS-band to offer these services. They may partner with public cloud providers to host some or all of the Aether public cloud components from the public cloud. In all of these

² The Aether pilot is running on the Google Cloud. It has also been tested on Microsoft Azure and AWS and could easily be hosted on a centralized telco cloud or centralized private enterprise cloud.

cases, operators would operate the network. While they may also manage the Aether edge sites, they may also partner with the 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 Aether Control and Management Platform and the mobile core control plane on public cloud, some others may choose to run them out of one of their own private data centers.

Clearly, there are other possible business models as well. Aether, with its modular architecture allowing its Control and Management Platform, and Connectivity-as-a-Service solution together, or separately to run 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 2, the Aether architecture is comprised of the following components:

1. Aether Control and Management Platform: The platform includes modules that allow for control and orchestration of multiple Kubernetes clusters at different locations, management of runtime Aether workflows that allow for adding new subscribers, new base stations, new edge clusters, new mobile core user planes to the operational network, monitoring tools as well as XOS™ - ONF's service mesh for connectivity VNFs. Aether Core is cloud agnostic and as such can run on Google Cloud, AWS, or Azure. It can also run on an operator's own central cloud, such as AT&T's AIC, or enterprise's own private data center. For ONF's Aether deployment, we run the Aether Core on Google Cloud, in a Highly-Available (HA) fashion.
2. Connectivity-as-a-Service: Also running on the central cloud (Google Cloud for our pilot network), is ONF's open source mobile core (OMEC™) control plane on a separate Kubernetes cluster, providing Connectivity-as-a-Service. This cluster is controlled by the Aether Control and Management Platform.
3. Aether Edge and Small Cells: Each edge location is furnished with sufficiently many small cells (CBRS for our pilot network) for coverage and end-user device density, and the Aether Edge. Aether Edge is effectively a highly scalable micro data center

composed of a leaf-spine fabric and servers. Depending on the enterprise size and desired use case, Aether Edge may be as small as a single switch and a single server. Running on the Aether Edge is one or more Kubernetes clusters, also managed by the Aether Control and Management Platform. These clusters host the virtualized central units (CU) of the small cells, ONF's open source mobile core (OMEC) user plane, ONOS® for fabric control, and in the near future, O-RAN compliant ONOS SD-RAN control.

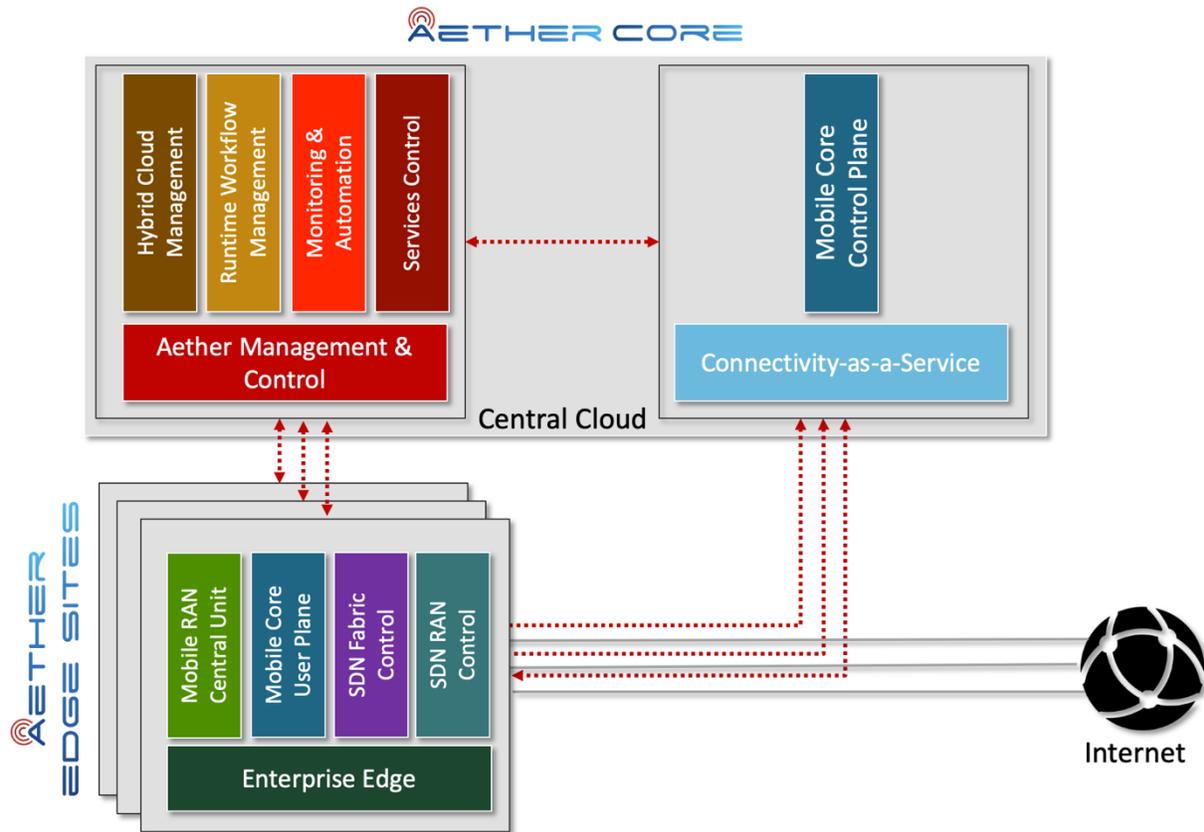


Figure 2: Aether Architecture

A critically important component of an operational cloud platform is its Application Programming Interfaces (APIs). An API simplifies the development of services and platforms by abstracting the underlying hardware and implementation and only exposing components or actions that developers need. Aether provides two distinct managed services in a multi-cloud environment: 5G/LTE connectivity and edge cloud control and management. As such, it needs to provide APIs for both. This means providing APIs for:

- Edge cloud infrastructure: Aether will support cloud APIs supported by major cloud providers for this purpose.

- SDN infrastructure: Aether Edge is built on an SDN infrastructure; it is based on an ONOS-controlled SDN fabric as well as an ONOS-controlled SD-RAN. Aether will provide SDN infrastructure APIs for developers to build applications that want to leverage and/or influence fabric and RAN state.
- 5G/LTE connectivity: Aether provides Connectivity-as-a-Service by distributing ONF's open source OMEC across edge and central clouds. OMEC is a disaggregated, user plane-control plane separated 3GPP-compliant mobile core. Aether will support APIs for developers to build applications that want to leverage and/or control subscriber, policy and network slice management.

As illustrated in Figure 3, Aether will also provide, as a managed service, an API Gateway which, in addition to exposing all of the above listed Aether APIs, will also simplify the creation, publication and maintenance of third party platform and service APIs for others to consume as part of the organic Aether API library.

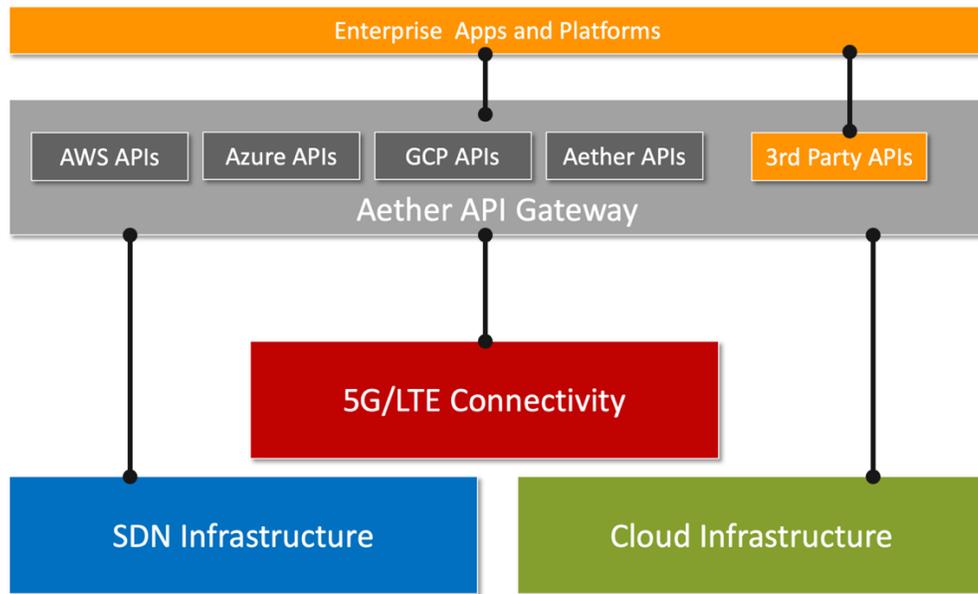


Figure 3: Aether's Upcoming API Gateway

Aether Pilot Deployment

Aether has been deployed at ONF's Menlo Park Office since December 2019. We have successfully connected Google Pixel 4 and iPhone 11 phones, 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. We are in

the process of scaling up the pilot by adding more edge locations, more connected devices, more device types, and new services for enterprise use such as IoT edge platforms, learning engines for operational automation, etc. As illustrated in Figure 3, by February 2020, the first two additional sites for Aether will be ONF’s Tucson office and Intel Lab’s Hillsboro location.

Aether is rapidly gaining significant interest in the industry. Currently, Intel, Infosys, Tech Mahindra and Accelleran are committed to becoming edge sites for Aether, with many more sites under discussion for joining the pilot in 2020.

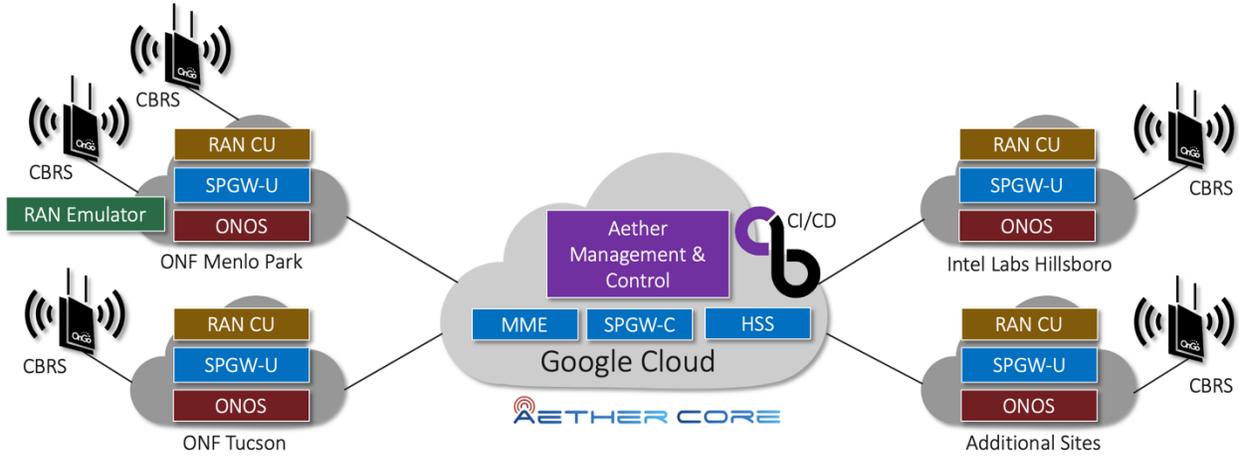


Figure 4: Aether Pilot Deployment

Lifecycle Management

Aether's attention to simplifying lifecycle management greatly lifts that burden from the enterprise. A CI/CD process and DevOps model provide for continuous improvement of the live operational network. Changes are first developed and tested in the staging network and then automatically pushed to the multi-cloud production network. This model dynamically delivers bug fixes, regression and operational testing, hardening, scaling, and new features without requiring end-user intervention.

The Aether distributed DevOps model currently marries developers from ONF, Intel, GS Lab, Infosys, and Accelleran into an agile development team collaborating and working towards deliverables with very tight deadlines. This work will continue even as new members join the project, the DevOps team grows, and as additional sites are deployed.

Aether's Relationship to Other ONF Projects

There are a number of on-going, interrelated projects at ONF, and Aether is highly synergistic and builds on this work.

Aether is built on the CORD® platform. As such, it leverages ONOS, Kubernetes, and XOS in its platform. It effectively disaggregates CORD to move some of its functionality to the public cloud and adds additional components to it on the path towards offering managed services.

Aether is SD-RAN ready. The ONF work developing an O-RAN compliant RAN solution with an ONOS-based Radio Intelligent Controller (RIC) will be integrated into Aether as soon as compliant small cells become available.

Aether uses OMEC as its mobile core. 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.

Last, but not least, Aether is an ideal 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, can readily be hosted on Aether to extend its current managed mobile connectivity offering towards a managed *converged* connectivity offering.

In addition, Aether has synergies with the Stratum project as well. The Aether Edge fabric may easily be constructed using Stratum. Further, the mobile core user plane, as well as the RAN CU user plane may be realized using the P4 paradigm to run on a Stratum-based fabric at the Aether edge sites.

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 everyone from the ONF ecosystem to actively

participate, collaborate and adopt this exciting new endeavor: develop new, innovative applications for enterprises on Aether, become part of the Aether pilot network and help us harden the platform, and help us add new, enterprise facing features to Aether's mobile connectivity.

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>