MODE

HIGHEST-PERFORMING SD-CORE

MODE CORE

HIGHEST-PERFORMING CORE NETWORK

+ True MPLS Reliability

+ Cloud Elasticity

+ Business-Internet Pricing

EXECUTIVE SUMMARY

Enterprise connectivity used to be simple.

Solutions like MPLS or VPLS were ideal for secure and reliable, albeit expensive, access to fixed locations and on-premises applications. So long as bandwidth requirements remained modest, and data and applications remained on-site, the status quo prevailed.

Those days are over.

Today, enterprises are more distributed than ever. Demand for bandwidth has increased exponentially. Enterprises have embraced the cloud and SaaS, and moved a significant portion of their mission-critical data and applications offsite. In the face of all this change, traditional, private connectivity solutions are too expensive, inflexible, and cloud-unfriendly. The market for enterprise connectivity is due for a makeover.

VPNs, VPCs, and technologies like SD-WAN, have flourished. They link offices, data centers, and cloud services, using inexpensive "business internet" connectivity. While they provide cloud-like setup and use, this flexibility comes at a significant cost – the lack of reliability guarantees for which traditional MPLS-based private networks are known. These new solutions leverage the internet for connectivity, and are therefore no more reliable than the internet itself.

SD-WAN: Managing Affordable vs. Reliable

SD-WAN promises to mitigate some of the downsides of MPLS, and help enterprises manage two disparate networks: MPLS for the mission-critical, and internet for everything else. SD-WAN offers easy set up, direct cloud access, centralized policy, transparent management, and affordability. Use of MPLS continues to grow, but enterprise use of the open internet is growing faster. Today's IT manager can choose quality or affordability. SD-WAN helps them manage this choice, but this choice – this compromise – must be made.

SD-CORE: Internet Core Alternative

SD-WAN has two primary functions: 1) the centralized creation and management of secure "tunnels" which connect multiple sites, and 2) the dynamic switching of last-mile delivery paths, based on content policies and network availability. In the SD-WAN model, traffic is directed either over MPLS at great cost, or the internet with inherent inconsistency, in particular latency variance. As shown in Figure 1, over 99.5% of all end-to-end Internet latency variance occurs in the core (first mile + middle mile) and not the last mile.

The variability of Internet performance has created demand for a software-defined core network alternative to the open internet, referred to as SD-CORE. The gold-standard SD-CORE would combine the true reliability of an MPLS network with the pricing of generic business internet. To achieve this, packet data performance would need to approach the limits allowed by physical law, something that is not achievable without a complete reinvention of a network's core routing algorithms. Evolutionary improvements like WAN optimization

and acceleration, caching, and TCP tuning are incapable of approaching this kind of performance. A breakthrough is required.

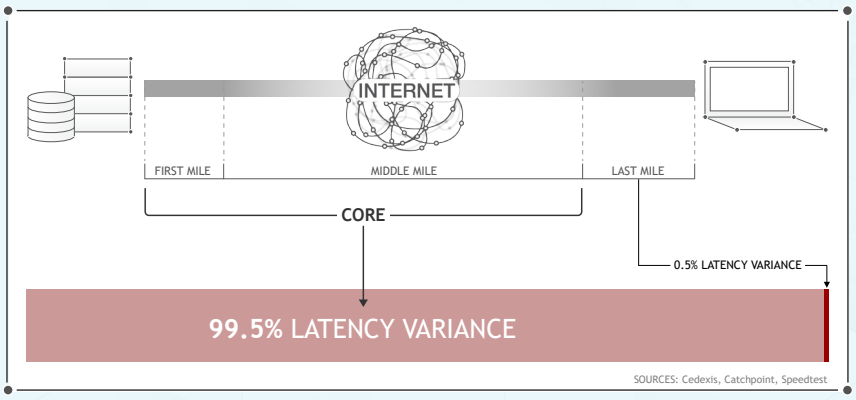

FIGURE 1: CORE LATENCY VARIANCE IS 99.5% OF TOTAL LATENCY VARIANCE

Mode Core: Ultimate SD-CORE

All of today's networks employ fixed routing techniques in layers 2 and 3 of the OSI model. The Mode mathematics discovery derives the pure math behind the optimal routing of data on a packet-switched network, and defines an unbreakable, theoretical limit of network performance. Mode has replaced ubiquitous fixed routing algorithms with this distributed, real-time routing algorithm. The result is a 10x cost/performance benefit. This revolutionary pure math backbone enables Mode to run the world's first fully autonomous, global IP network – a true SD-CORE – offering the actual reliability of MPLS at a business-internet price point. We call this network Mode Core.

Mode Core enhances SD-WAN, and provides an affordable QoS path for enterprise traffic between SD-WAN-enabled corporate offices and data centers. Mode Core uses this same, reliable path to connect to public cloud, private cloud, and SaaS services like unified communications. In Mode Core, multipoint VPN tunnels traverse a private core network that comes with the same reliability and guarantees as expensive MPLS solutions.

Coupling any SD-WAN solution with Mode Core means businesses can gracefully phase their transition from MPLS to another QoS network that also offers MPLS-like availability and SLA guarantees. Even a small amount of this transition can pay for an entire SD-WAN implementation. Mode Core also offers instant elastic bandwidth scaling, network creation in under a minute, and unlimited micro-segmentation by application. In the face of exploding bandwidth use, businesses can ultimately turn to one, truly affordable SLA-backed QoS core network for nearly everything.

Today, Mode is redefining business connectivity. Tomorrow, we're reinventing the internet itself.

ENTERPRISE CONNECTIVITY IN THE AGE OF CLOUD MIGRATION

For many years, enterprise WAN connectivity was a well-understood problem, with predictable solutions. Offices and data centers could be linked using MPLS or VPLS, and carriers would offer standard performance guarantees. Applications, services, and the network, were under the control of the CIO. Problems with the network were fielded by the MPLS provider. This traditional connectivity market has flourished to the present day, with millions of enterprise customers spending $40-50B annually.

Time changes most things, and paradigms of enterprise connectivity are no exception. Over the last decade, enterprise data traffic has exploded in volume. The use of the public internet has contributed significantly to this increase. In 2007, global enterprises transported about 400 petabytes per month of data over traditional private networks. By contrast, monthly enterprise traffic over the public internet was considerably smaller (Cisco VNI). By 2016, things had changed dramatically: enterprise private WAN traffic had increased to 3,300 petabytes per month (projected to grow 10% per year), and enterprise internet traffic dwarfed private WAN connectivity at 13,000 Petabytes per month (growing at twice the private WAN rate). Mobile and remote enterprise connectivity had become standard practice for most employees, resulting in a 41% CAGR for mobile enterprise data usage (Cisco VNI).

The rigid office-to-office enterprise structure shown in Figure 2 . . .

FIGURE 2: PRE-CLOUD ENTERPRISE

. . . has given way to the flexible, dynamic, distributed enterprise of today:

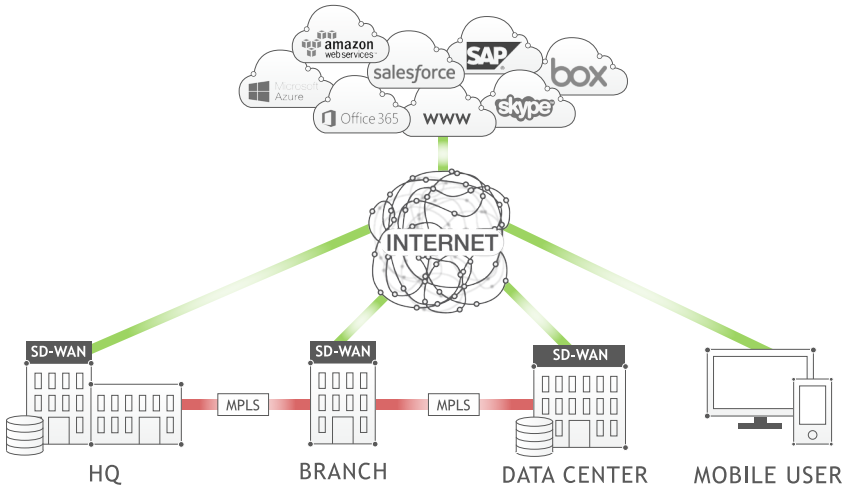

FIGURE 3: HYBRID ENTERPRISE

Today, for every unit of enterprise traffic sent over MPLS, five times that traffic is sent by the same business over an internet connection. Applications are driving this dramatic change:

Remote Access: The global workforce has become increasingly mobile and remote. By 2020, nearly half of the enterprise workforce will operate outside of headquarters (Quartz, March 2013). Remote users cannot use private WAN solutions to access enterprise resources, and have turned to the internet instead.

Unified Communications (UC): The UC market has grown into a $20B industry that contributes significantly to enterprise network consumption. Video conferencing and VOIP services represent $12B of this market, and represent a significant source of consumption external to the enterprise, thereby driving WAN bandwidth use.

Hybrid Clouds: Today, 30-50% of all enterprise traffic can be attributed to accessing cloud services (Cisco, 2013). By 2020, 40% of all enterprise applications will move to cloud (Gartner, 2016). Unsurprisingly, 90% of all cloud access uses an internet connection.

THE QUALITY VS. CONVENIENCE DILEMMA

It is hard to beat the sheer convenience of the internet: it is affordable, open, and easily scaled. Despite its inherent advantages, the internet has not displaced MPLS as the tool of choice for enterprise. The reason: reliability guarantees. Internet variability, and its impact on enterprise applications, has kept many mission-critical applications on MPLS. Internet variability can be measured in several ways, including observing the difference between median and peak traffic. The chart below highlights this increased variability: as of 2016 the deviation is well over 300%, and is projected to double by 2021.

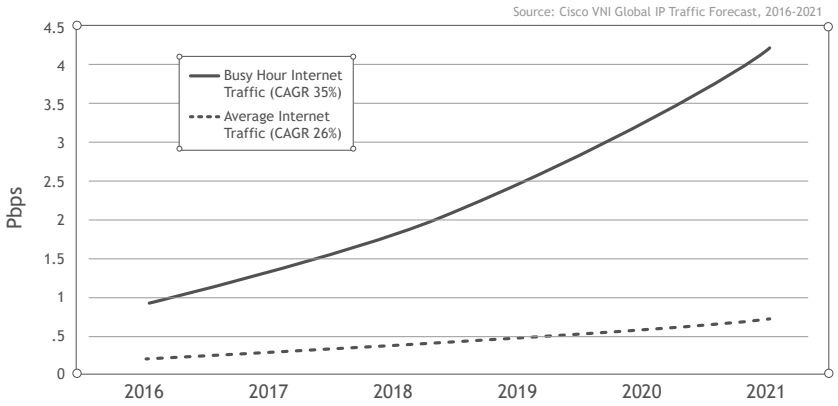

FIGURE 4: INTERNET 'BUSY HOUR' COMPARED TO AVERAGE TRAFFIC

SLA-backed reliability, core security, and interoffice connectivity, remain the primary drivers of MPLS usage. SD-WAN over internet addresses the latter two, but fails to deliver the reliability of a private network. Businesses still need to choose affordability or reliability for different applications and data.

SD-WAN:
THE NEED FOR A RELIABLE INTERNET CORE ALTERNATIVE

Reliability

SD-WAN over internet cannot deliver SLA-backed reliability to enterprise. This has become the most significant impediment to the growth of SD-WAN. Although SD-WAN revenues have grown to $500M in 2017, they have done little to slow the growth of the 100X larger MPLS market, which broke new records in the very same year. SD-WAN growth has been limited to converting enterprise interoffice connectivity installations, where cost outweighs reliability (e.g. distributed manufacturing and retail installations). SD-WAN cannot address the entire $50B enterprise MPLS market until the transport core of SD-WAN is competitively reliable.

Core Network

SD-WAN came to market as the result of networking breakthrough: the ability of software-defined networking to deliver centralized control plane orchestration, in conjunction with edge network data plane path switching, at one-tenth the price of MPLS. SD-WAN's ability to enter the much larger, quality-conscious, enterprise connectivity market hinges on commercialization of another breakthrough: a fully software-orchestrated, QoS core network, offered at a business-class internet price. This is the Mode vision of an SD-CORE, combining the benefits of SD-WAN implementations with the reliability guarantees of an MPLS network (Figure 5). This ultimate SD-CORE would work side-by-side with MPLS, allowing businesses to safely phase their transition from MPLS to an elastic QoS network with business-internet bandwidth pricing. Even a small amount of such a transition would pay for an entire SD-WAN implementation.

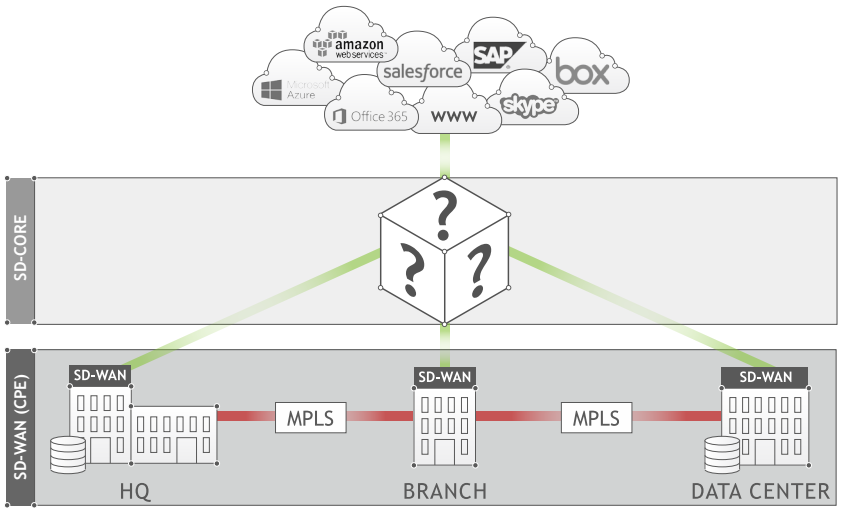

FIGURE 5: SD-CORE BRINGS AFFORDABLE QoS TO SD-WAN

Ultimate SD-CORE

An ultimate SD-CORE delivers the reliability guarantees of MPLS via a fully software-defined private network that obviates the need for dedicated, per-customer "circuits." Instead, a multi-tenant software control plane orchestrates traffic delivery tailored to the QoS needs of each individual enterprise. The customer network is dynamically crafted from the underlay capacity, allocating

bandwidth for each enterprise in real time. Bandwidth allocation is dynamic, allowing an enterprise to buy capacity on the network, and use it anywhere. Enterprises maintain full end-to-end visibility and control, with access to intrinsic software data gathering and analytics: managing their WAN just like their LAN.

SD-WAN + Ultimate SD-CORE

The result of combining these two technologies is the world's first high-performance, dynamic, end-to-end WAN for enterprise, backed by reliability guarantees, and offered at business-internet pricing. SD-WAN provides edge switching, and secure, multi-point VPN across enterprise locations. An ultimate SD-CORE adds a reliable, SLA-backed, private QoS underlay to SD-WAN, optimally routing traffic between enterprise sites, data centers, and the cloud. The following table compares MPLS, traditional SD-WAN, and SD-WAN enhanced with the Mode vision of an SD-CORE:

	MPLS	SD-WAN Internet + MPLS	SD-WAN Internet + Ultimate SD-CORE + MPLS
Site-to-Site Connectivity	✓	✓	✓
QoS	✓	MPLS Only	✓
High Core Availability + SLA	✓	MPLS Only	✓
Cloud/SaaS Connectivity	✗	✓	✓
Easy, Transparent Management	✗	✓	✓
Remote Access	✗	✗	✓
Instant Bandwidth Scaling (High Availability)	✗	✗	✓
Safe, Phased Transition from MPLS	—	✗	✓
Instant Network Creation (High Availability)	✗	✗	✓
Micro-Segmentation by Application	✗	✗	✓
Cost/Mbps (High Availability)	$$$	$$$	$ (As low as business internet)

This SD-WAN + Ultimate SD-CORE combination optimally addresses the primary use cases driving today's enterprise traffic, with fully guaranteed reliability:

- **Remote Access** users route their traffic over SD-CORE, and receive the same reliability guarantees of enterprise LAN.
- **Unified Communications** applications route over SD-CORE, and benefit from the loss, latency, and jitter guarantees of local implementations.
- **Cloud and SaaS** applications, accessed end-to-end over SD-CORE, get the same performance guarantees of data center-based enterprise apps over MPLS

MODE CORE:

MATH BUILDS THE BEST SD-CORE

Mode conceives of the ideal SD-CORE as a global SDN with:

- QoS, MPLS-like availability, with the reliability guarantees of MPLS
- the simplicity of SD-WAN
- equalized connectivity between physical sites, remote users, cloud, and SaaS applications
- business-class internet pricing

Existing SDN solutions are incapable of offering the entirety of this SD-CORE feature set, absent a significant breakthrough in network transport efficiency applied at layers 2 and 3. That breakthrough is the Mode HALO algorithm. Mode Core is the first commercial application of Mode HALO in pursuit of our vision of an ideal SD-CORE (Figure 6).

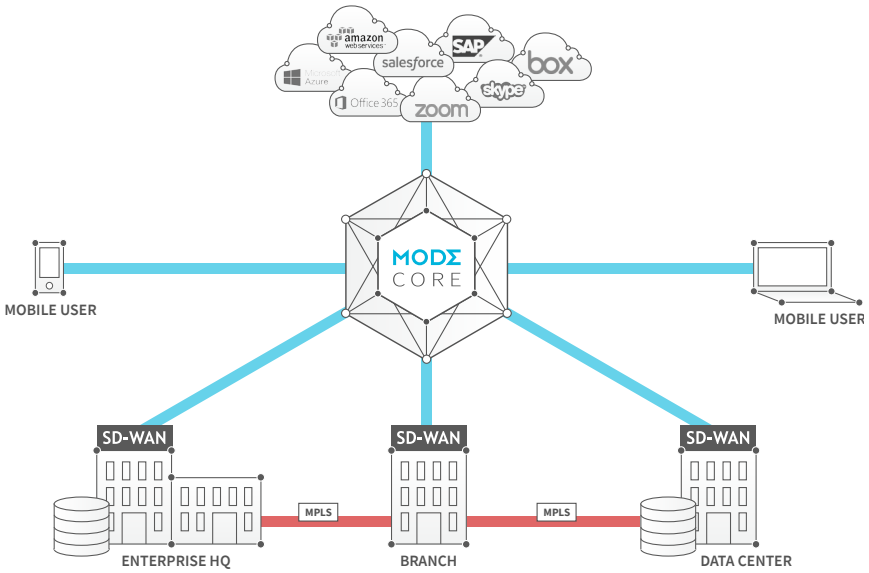

FIGURE 6: MODE CORE

Mode Core is the first fully autonomous, real-time SDN. Mode Core control and data planes are implemented solely in software, and reside on cloud blade servers that are interconnected with dedicated fiber (wavelength) among PoPs. The original Mode HALO algorithms were developed as part of Cornell's HALO project, by Mode founders Nithin Michael (PhD, EE) and Kevin Tang (PhD, EE). Mode Core achieves autonomous control by implementing the Mode HALO distributed optimal control algorithm.

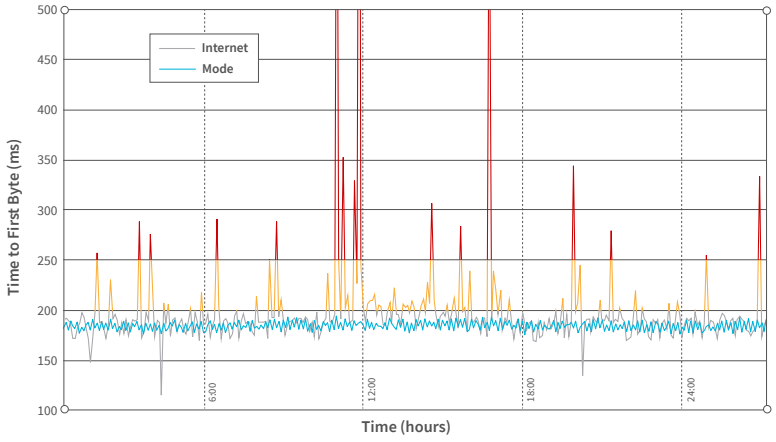

FIGURE 7: INTERNET VS. MODE CORE - WASHINGTON, DC TO TOKYO

Mode HALO has the unique ability to re-route traffic in milliseconds based on real-time feedback. Performance tests using large-networks (National Science Foundation, AT&T Network Challenge, and others) have consistently showcased the unique ability of Mode HALO to converge to optimal routing paths within seconds of major traffic changes. Mode HALO delivers up to 10x the performance of traditional networks, putting the promise of SD-CORE within reach.

The Breakthrough

In September of 2014, IEEE Transactions on Networking published a paper by two Cornell PhDs featuring HALO, a ground-breaking, algorithmic approach to distributed and real-time optimal network routing (https://people.ece.cornell.edu/atang/pub/15/HALO_ToN.pdf). In this paper, Professor Kevin Tang and Ph.D. candidate Nithin Michael provided the first mathematical derivation of the characteristic equations governing all packet-switched networks. Using these equations, Tang and Michael were further able to implement a mathematically optimal distributed control system that could control packet-switch networks with a response time measured in milliseconds (the HALO algorithm).

$$
\begin{aligned}
\text{If } r_u^t > 0, \qquad \dot{a}_{u,v}^t &= -\frac{a_{u,v}^t \delta}{\eta_u^t r_u^t}, \qquad v \neq \bar{v} \\
\dot{a}_{u,\bar{v}}^t &= -\sum_{v:(u,v)\in\mathbb{E}} \dot{a}_{u,v}^t \qquad v \neq \bar{v} \\
\text{else if } r_u^t = 0, \qquad a_{u,v}^t &= 0, \qquad v \neq \bar{v} \\
a_{u,\bar{v}}^t &= 1.
\end{aligned}
$$

FIGURE 8: THE HALO EQUATIONS

HALO Test Results

Between 2014 and 2016, a series of national tests were performed to validate the efficacy of the HALO algorithm. These included a throughput/latency test conducted by the National Science Foundation across its GENI national test network, and a subsequent evaluation of optimal path calculation via the AT&T SDN Innovation Challenge.

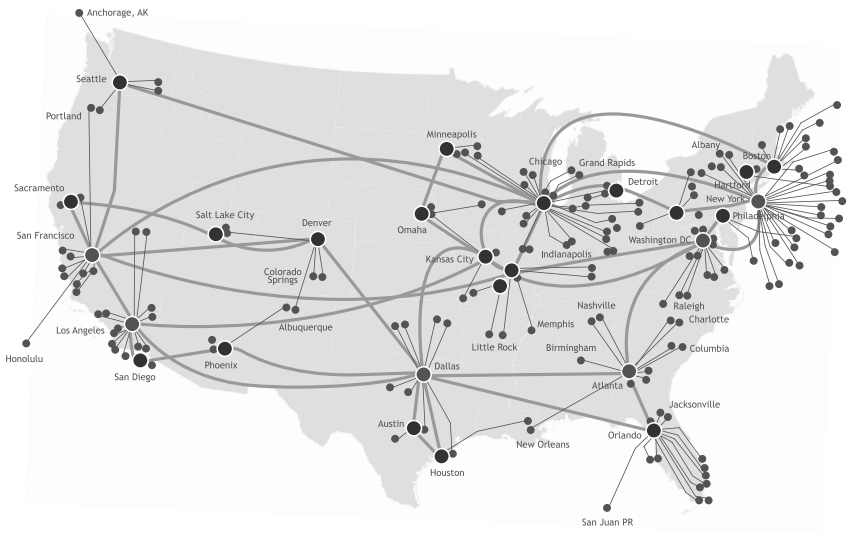

FIGURE 9: AT&T CHALLENGE NETWORK

The NSF test validated that the new SDN implementation of HALO enabled the network to deliver 3x the traffic of the second-best algorithm, along with best-in-class latency at the physical limit, and with the near elimination of variance. HALO subsequently won the AT&T Challenge, a complex 200+ node routing problem complicated by enormous traffic loads, by converging to near-optimal routing in 30 seconds.

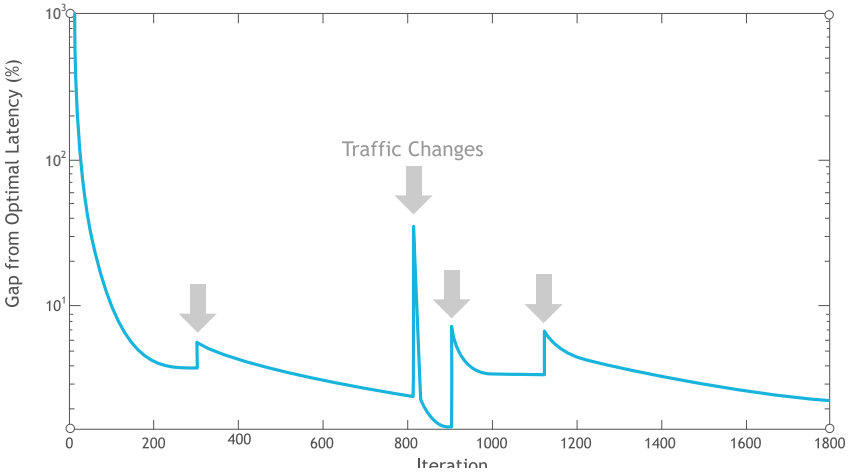

FIGURE 10: HALO OPTIMAL CONVERGENCE PATTERNS

MODE CORE:

AUTONOMOUS GLOBAL NETWORK

Mode was founded in 2014 by the inventors of HALO, Kevin Tang and Nithin Michael. With support from NEA, Google, and the NSF, HALO became Mode HALO, and its first commercial implementation was introduced: Mode Core. Mode Core is the world's first fully autonomous, SD-WAN compatible, private network, offering QoS connectivity at business-internet pricing. Mode Core leverages the Mode HALO mathematics discovery to achieve a 10X design and implementation cost advantage over traditional telco networks. The Mode Core SDN implementation provides a robust set of capabilities ensuring simple operation and management. Enterprise customers can instantiate a dedicated, global QoS private network in around 60 seconds. Enterprise administrators can use the Mode Core dashboard to see network performance metrics (e.g. loss, latency, jitter, utilization), user access, and traffic flows.

MODE

APPLICATIONS

UNIFIED COMMUNICATIONS

Eliminate internet unreliability by running your unified communications applications on Mode Core.

PROBLEM

- Unified communications is a valuable productivity tool, but internet variability causes inconsistent performance.
- Frequent dropped connections, blurry video, and poor audibility result in user frustration, lower productivity, and revenue loss
- Unpredictable performance can vary by time of day, video quality, number of participants, and/or geography
- Private connectivity solutions deliver reliability, but are often logistically inflexible or prohibitively expensive

PURE WAN SOLUTION

- Global worldwide performance for your mission-critical unified communications applications via the world's most-efficient global private network, with local nodes from home to Hamburg to Hong Kong
- Solid, high-performing, multi-participant unified communications, immune to time of day or distance of location, and independent of the inconsistencies of the open internet

IMPLEMENTATION

- A simple DNS change redirects traffic to the nearest geographical PoP on Mode Core
- Integration and peering relationships exists with major service providers
- No change to existing infrastructure
- No software or hardware to install

REMOTE ACCESS

Eliminate the variability of the internet by optimizing access to existing VPN infrastructure with Mode Core.

PROBLEM

- Unreliable VPN performance based on time of day, data volume, or geography
- Inconsistent VPN performance due to the inherent unreliability and variability of the open internet
- Poor VPN performance means lost productivity, increased support costs, and unhappy users

PURE WAN SOLUTION

- Global worldwide access to your VPN service via dynamic, optimal routing over Mode Core, with local nodes from home to Hamburg to Hong Kong
- Solid, unwaveringly consistent, optimal VPN performance – regardless of time of day or distance of location, and independent of the inconsistencies of the open internet
- Mode Core uses an agentless model and supports SSL and IPsec

IMPLEMENTATION

- A simple DNS change redirects traffic to the nearest geographical PoP on Mode Core
- No change to the existing VPN infrastructure or VPN client is required; zero perturbation of end-to-end VPN security
- No software or hardware to install

APPLICATIONS

MODE

CLOUD CONNECT

Eliminate the variability of the internet and drastically improve cloud application experience by optimizing access to cloud applications and infrastructure with Mode Core.

PROBLEM

- Inconsistent cloud performance based on time of day, data volume, or geography
- Unreliable application performance due to the inherent unreliability and variability of the open internet
- Inconsistent security policies across cloud and on-premises applications
- No visibility into cloud application usage
- Poor performance leads to lost productivity, increased support costs, and unhappy users

PURE WAN SOLUTION

- Global worldwide access to your cloud applications via the most-efficient global private network, with local nodes from home to Hamburg to Hong Kong.
- Solid unwaveringly consistent, optimal performance – regardless of time of day or distance of location, and independent of the inconsistencies of the open internet

IMPLEMENTATION

- A simple DNS change redirects traffic to the nearest geographical PoP on Mode Core
- Integration and peering relationships exists with major service providers
- No change to existing infrastructure
- No software or hardware to install

SITE CONNECT

Go big on bandwidth with a secure, SLA-backed, business-class QoS site-to-site connectivity solution that is cloud and mobile-ready, and priced at flexible business-internet rates.

PROBLEM

- Unreliable application performance due to the inherent unreliability and variability of the open internet
- MPLS and other private connectivity services are too expensive and don't scale with traffic demands
- Inconsistent security policies across cloud and on-premise applications
- No visibility into application usage
- Poor performance translating into lost productivity, increased support costs, and unhappy users

PURE WAN SOLUTION

- Global worldwide connectivity for your global enterprise via the most-efficient global private network, with local nodes from home to Hamburg to Hong Kong
- Solid, unwaveringly consistent, optimal performance – regardless of time of day or distance of location, and independent of the inconsistencies of the open internet
- SLA-backed, QoS private connectivity at business-internet pricing

IMPLEMENTATION

- Integration with most SD-WAN vendors and with standard CPEs
- Strategically located PoPs around the world
- No change to existing infrastructure
- No software or hardware to install

MODΣ

HIGHEST-PERFORMING SD-CORE

SUMMARY

Cloud computing has fundamentally altered enterprise WAN connectivity needs. Traditional solutions like MPLS are too inflexible and expensive to support a successful enterprise cloud strategy. Mode Core enhances SD-WAN with an SLA-backed, private QoS network for enterprise with the true reliability of MPLS, and the pricing of business internet. Mode gives businesses the ability to transition gracefully from MPLS to another QoS network with high availability and SLA guarantees. Mode Core works with any SD-WAN solution, and offers instant elastic bandwidth scaling, complete end-to-end visibility, instant QoS network creation, unlimited micro-segmentation by application, and an incredible ROI. Mode connects remote users, enterprise sites, and cloud-based assets, and enhances unified communications and SaaS applications – with QoS and reliability guarantees, and at a business-internet price point.

ABOUT MODE

Mode operates the world's highest-performing software-defined core network (SD-CORE), built around a real-time network control breakthrough. Mode was co-founded by two Cornell computer scientists widely recognized for their discovery of the characteristic equations that define modern packet-switched networks, and their subsequent implementation of a mathematically optimal routing system, Mode HALO. Mode Core powers SD-WAN, Cloud Access, Unified Communications (UC), and Ultra Low Latency applications. Mode Core enhances any enterprise WAN by providing reliable, QoS connectivity in combination with cloud elasticity and business-internet pricing. Mode is based in San Francisco, and backed by GV, NEA and the NSF.