SDN for the Cloud

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This presentation is the work of a large team

Acknowledgements

This presentation describes work done by Microsoft Azure Networking team, that builds on many ideas from Academia, Azure, Microsoft Research, Bell Labs, etc.

The results are a full Software-defined Network system that runs one of the biggest public clouds on the face of the earth.

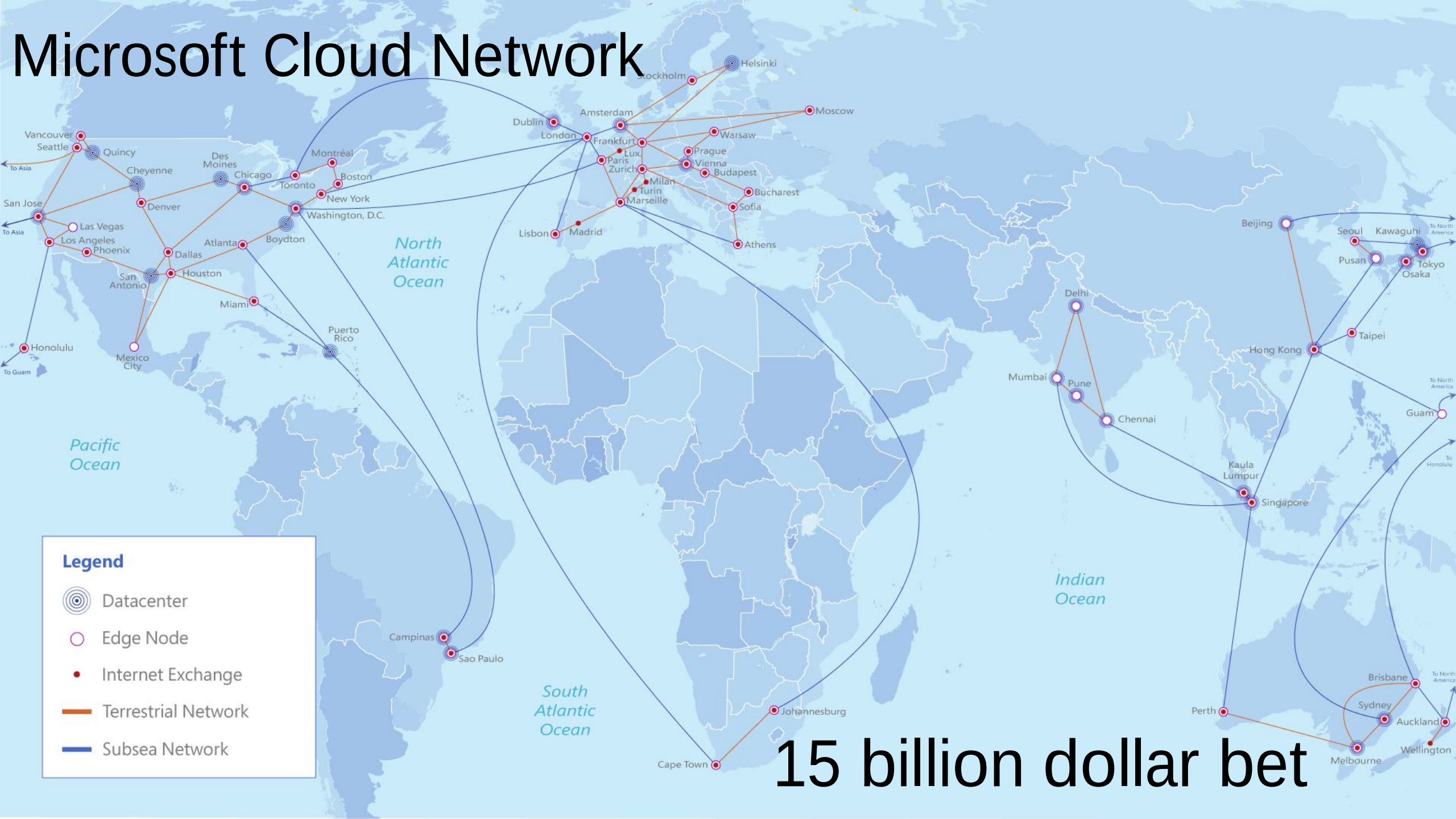
Cloud provided the killer scenario for SDN

- Cloud has the right scenarios
  - Economic and scale pressure → huge leverage
  - Control → huge degree of control to make changes in the right places
  - Virtualized Data Center for each customer → prior art fell short
- Cloud had the right developers and the right systems
  - High scale fault tolerant distributed systems and data management

At Azure we changed everything because we had to, from optics to host to NIC to physical fabric to WAN to Edge/CDN to ExpressRoute (last mile)

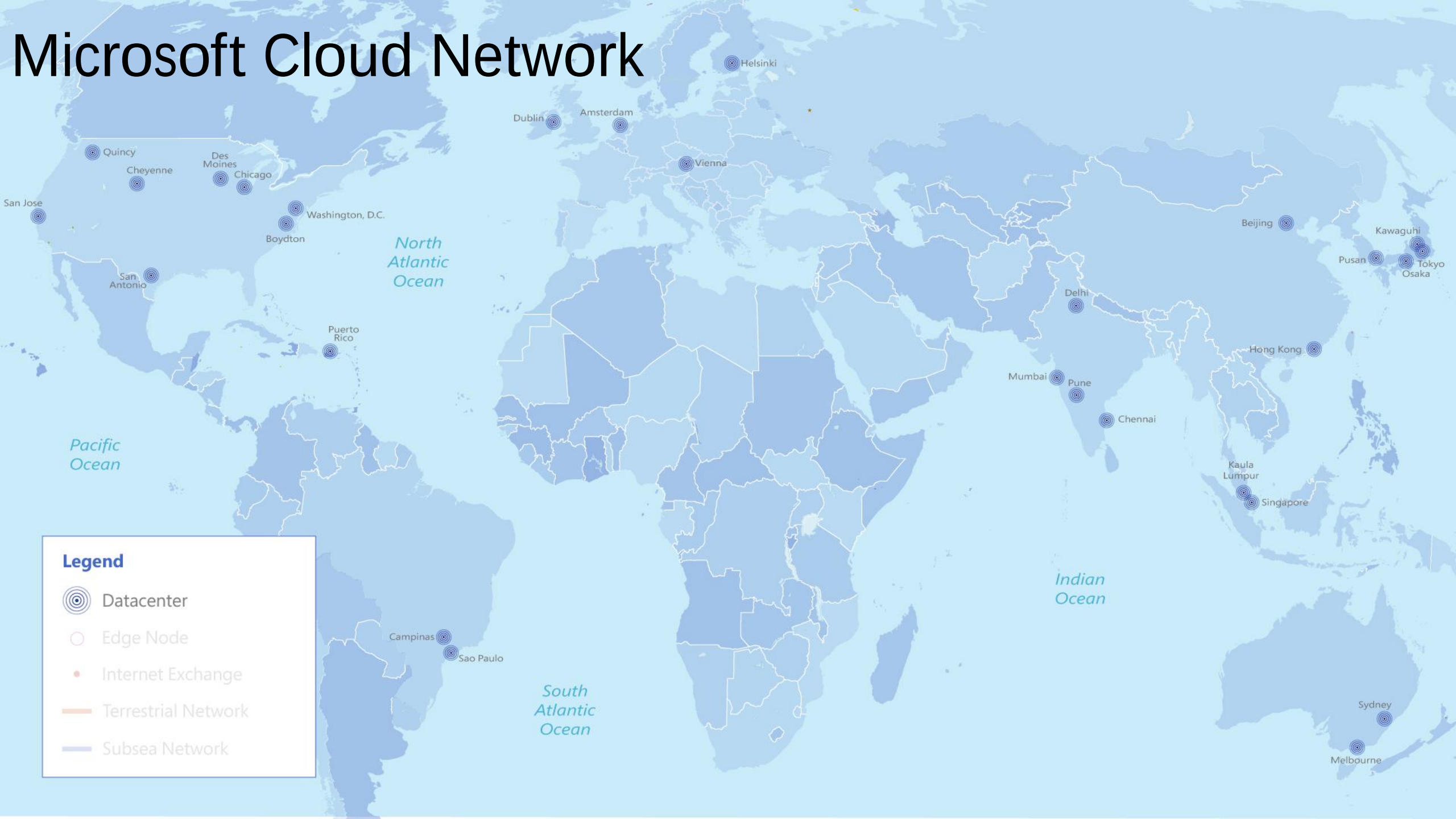
Hyperscale Cloud

Microsoft Cloud Network

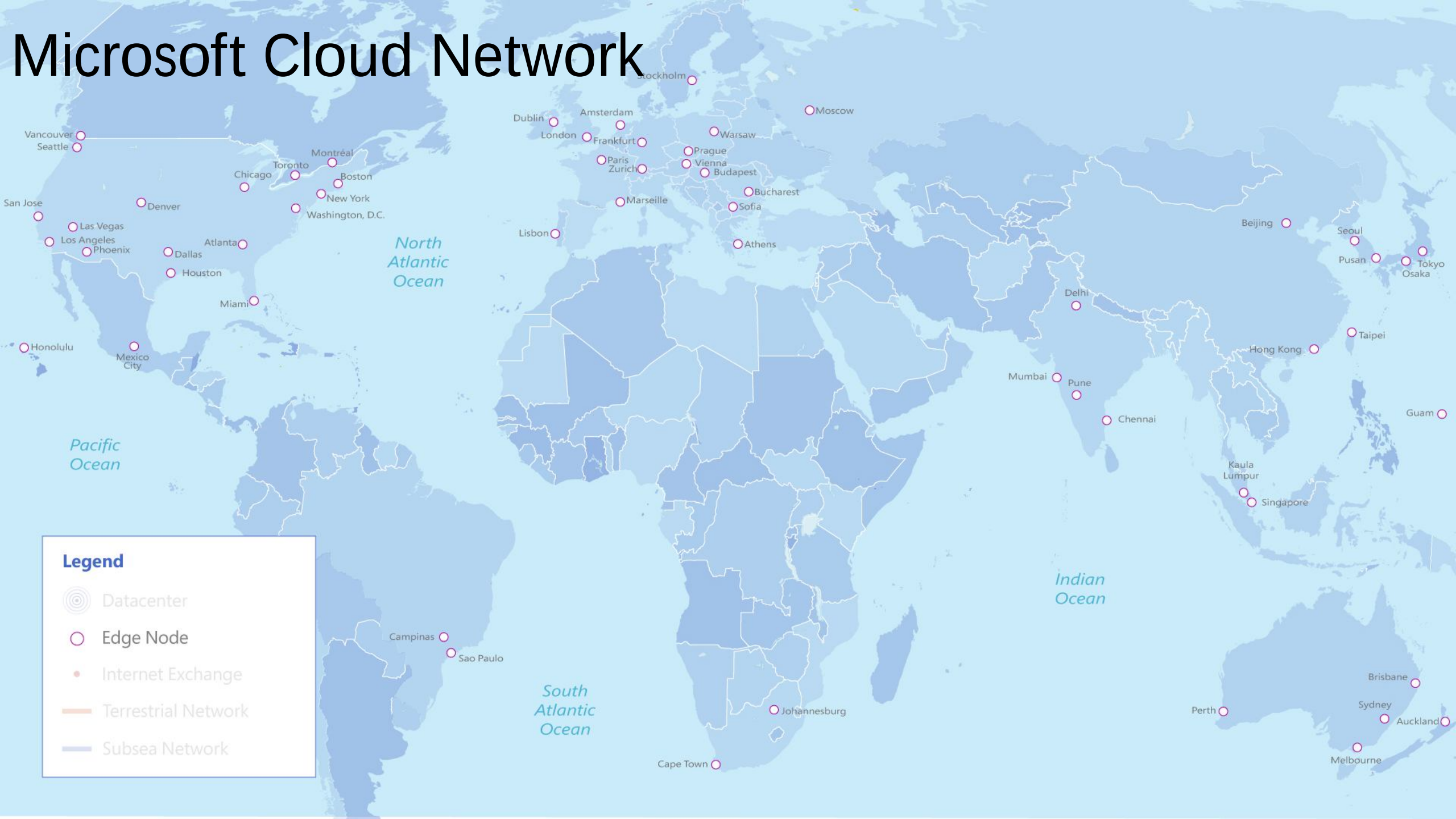


15 billion dollar bet

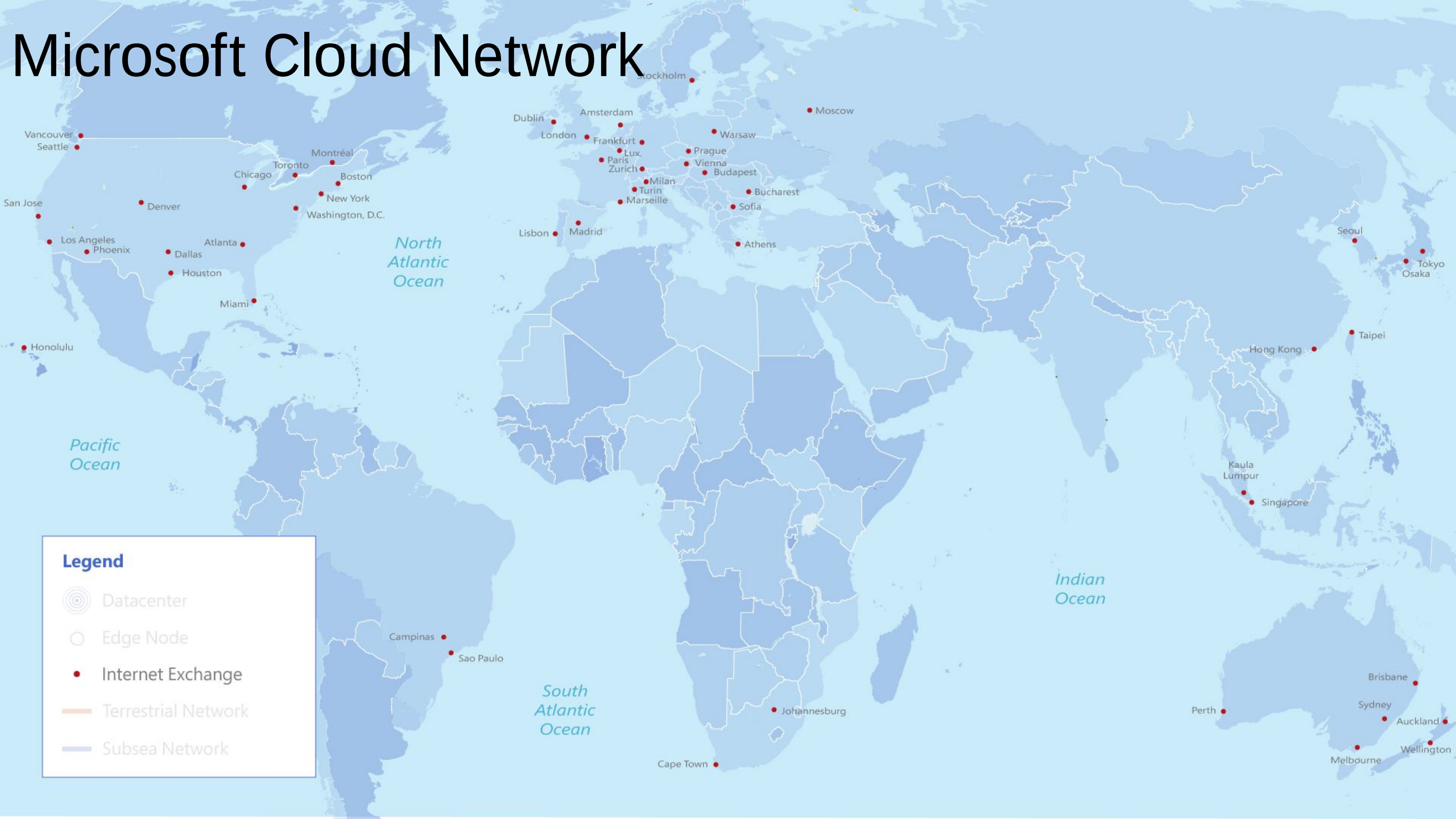
Microsoft Cloud Network



Microsoft Cloud Network

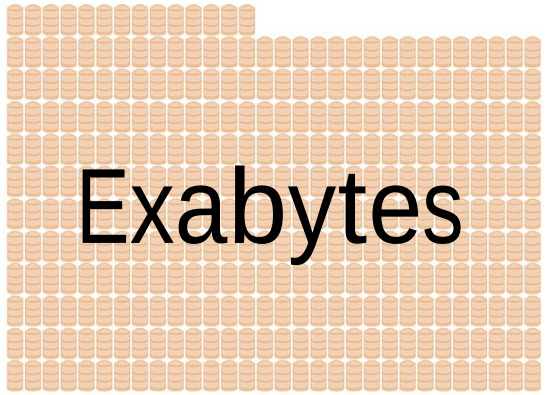
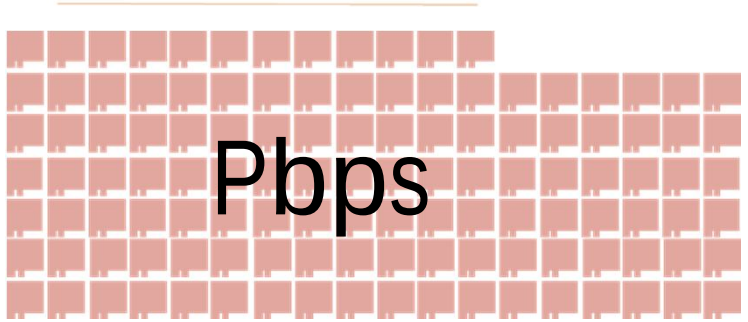


Microsoft Cloud Network



Microsoft Cloud Network

ExpressRoute Sites and Partners

	2010	2015
Compute Instances	100K 	Millions 
Azure Storage	10’s of PB 	Exabytes 
Datacenter Network	10’s of Tbps 	Pbps 

Scale

>85%
Fortune 500 using Microsoft Cloud

425 **MILLION**
Azure Active Directory users

1 **TRILLION**
Azure Event Hubs events/month

>93,000
New Azure customers a month

>18 **BILLION**
Azure Active Directory authentications/week

>60 **TRILLION**
Azure storage objects

>5 **MILLION**
requests/sec

1 out of 4 Azure VMs are Linux VMs

1,400,000
SQL databases in Azure

Microsoft

Agenda

Consistent cloud design principles for SDN

Physical and Virtual networks, NFV

Integration of enterprise & cloud, physical & virtual

Future: reconfigurable network hardware

Career Advice

Cloud Design Principles

Scale-out multi active path data plane

Embrace and Isolate failures

Centralized control plane: drive network to target state

Resource managers service requests, while meeting system wide objectives

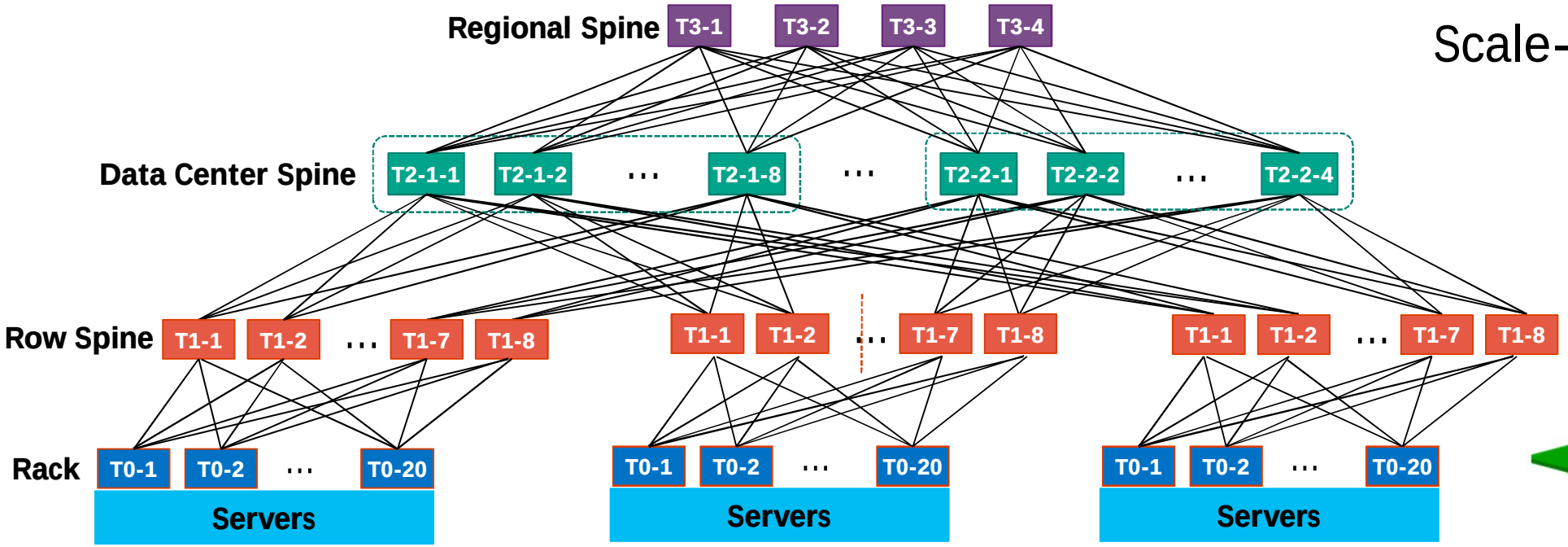
Controllers drive each component relentlessly to the target state

Stateless agents plumb the policies dictated by the controllers

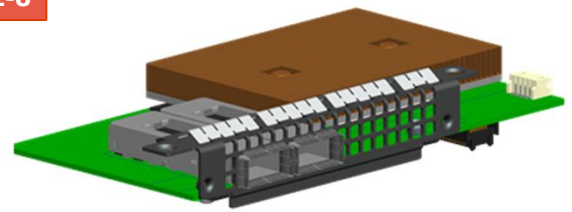
These principles are built into every component

Hyperscale Physical Networks

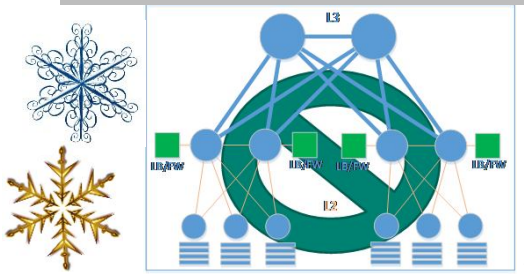
VL2 → Azure Clos Fabrics with 40G NICs



Scale-out, active-active



Scale-up, active-passive



Outcome of >10 years of history, with major revisions every six months

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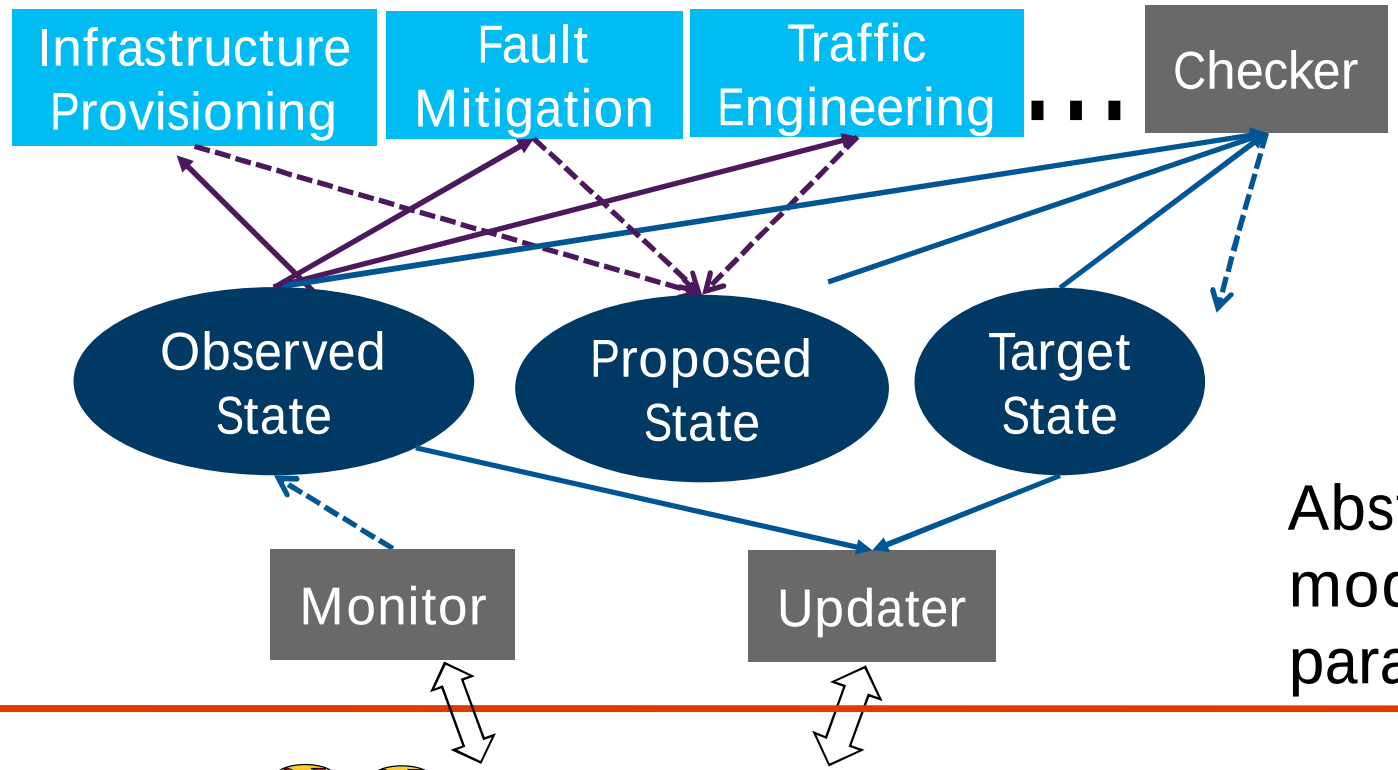
Challenges of Scale

- Clos network management problem
  - Huge number of paths, ASICs, switches to examine, with a dynamic set of gray failure modes, when chasing app latency issues at 99.995% levels
- Solution
  - Infrastructure for graph and state tracking to provide an app platform
  - Monitoring to drive out gray failures
  - Azure Cloud Switch OS to manage the switches as we do servers

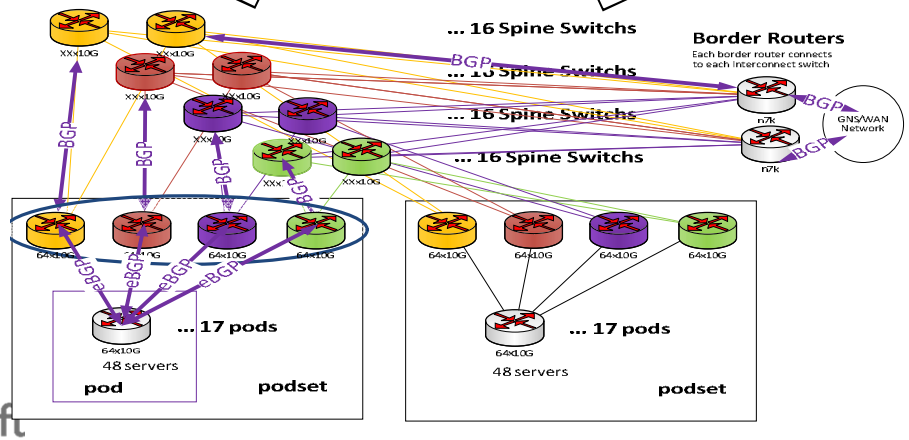
Capex $/Tbps and Opex are 100X smaller than counterparts for prior networks

Azure State Management System Architecture



Centralized control plane: drive network to target state

Abstract network graph and state model: the basic programming paradigm



High scale infrastructure is complex: multiple vendors, designs, software versions, failures

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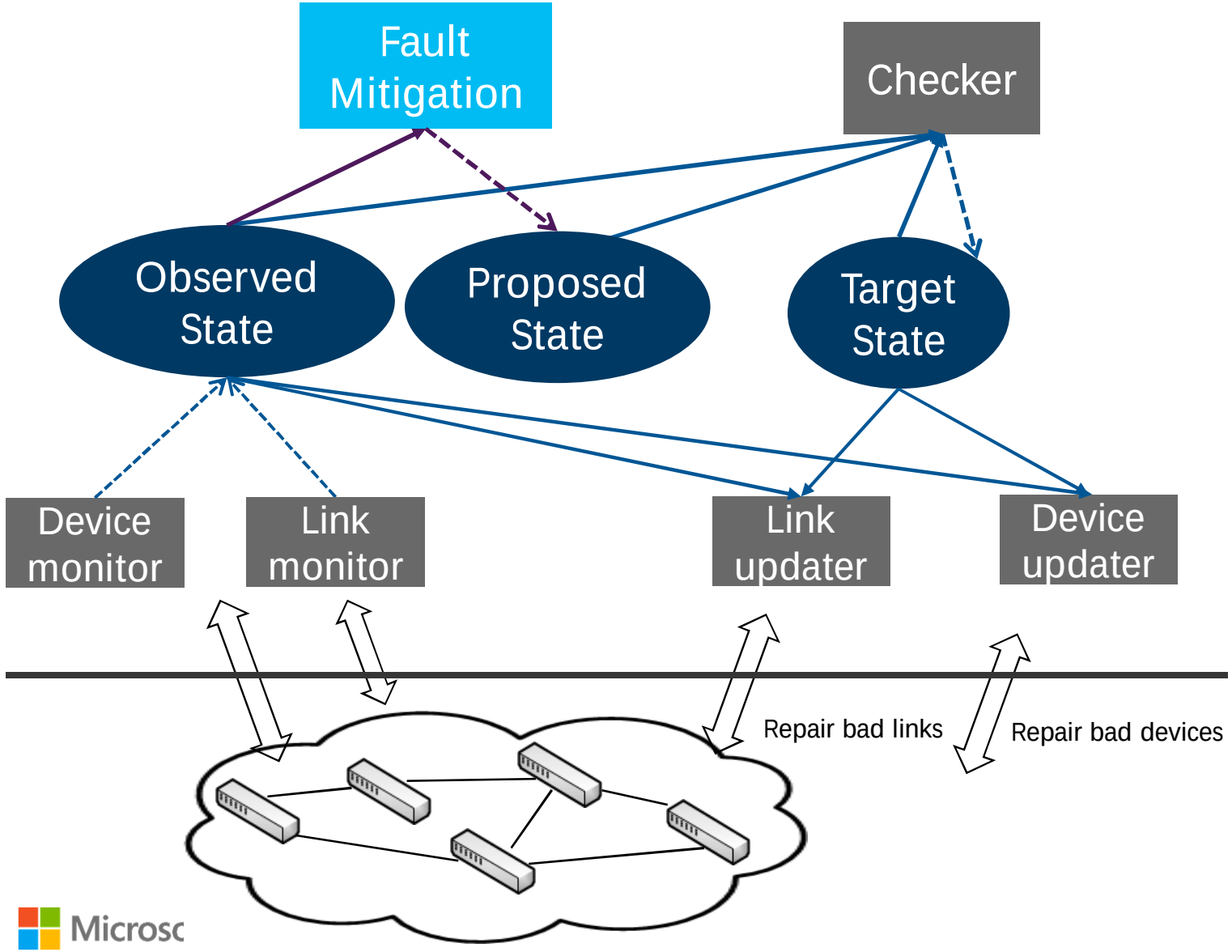
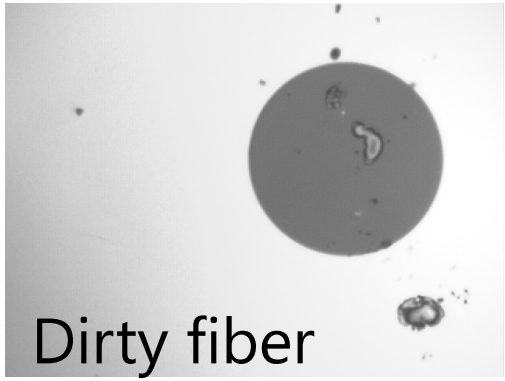
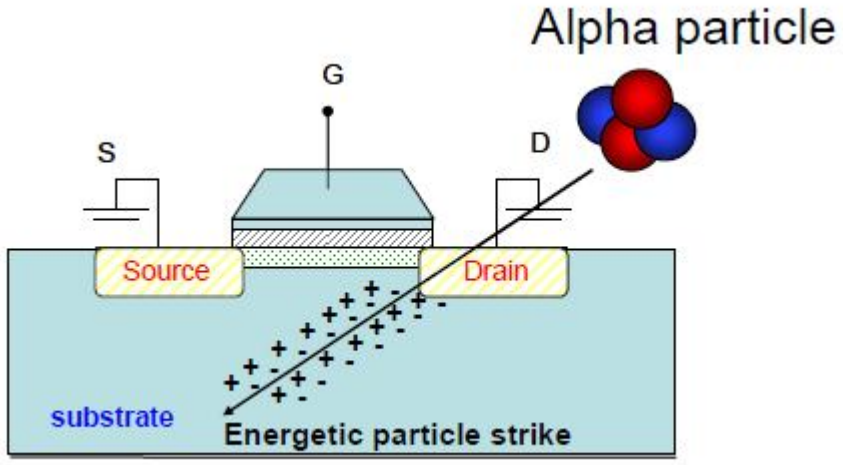
App I: Automatic Failure Mitigation

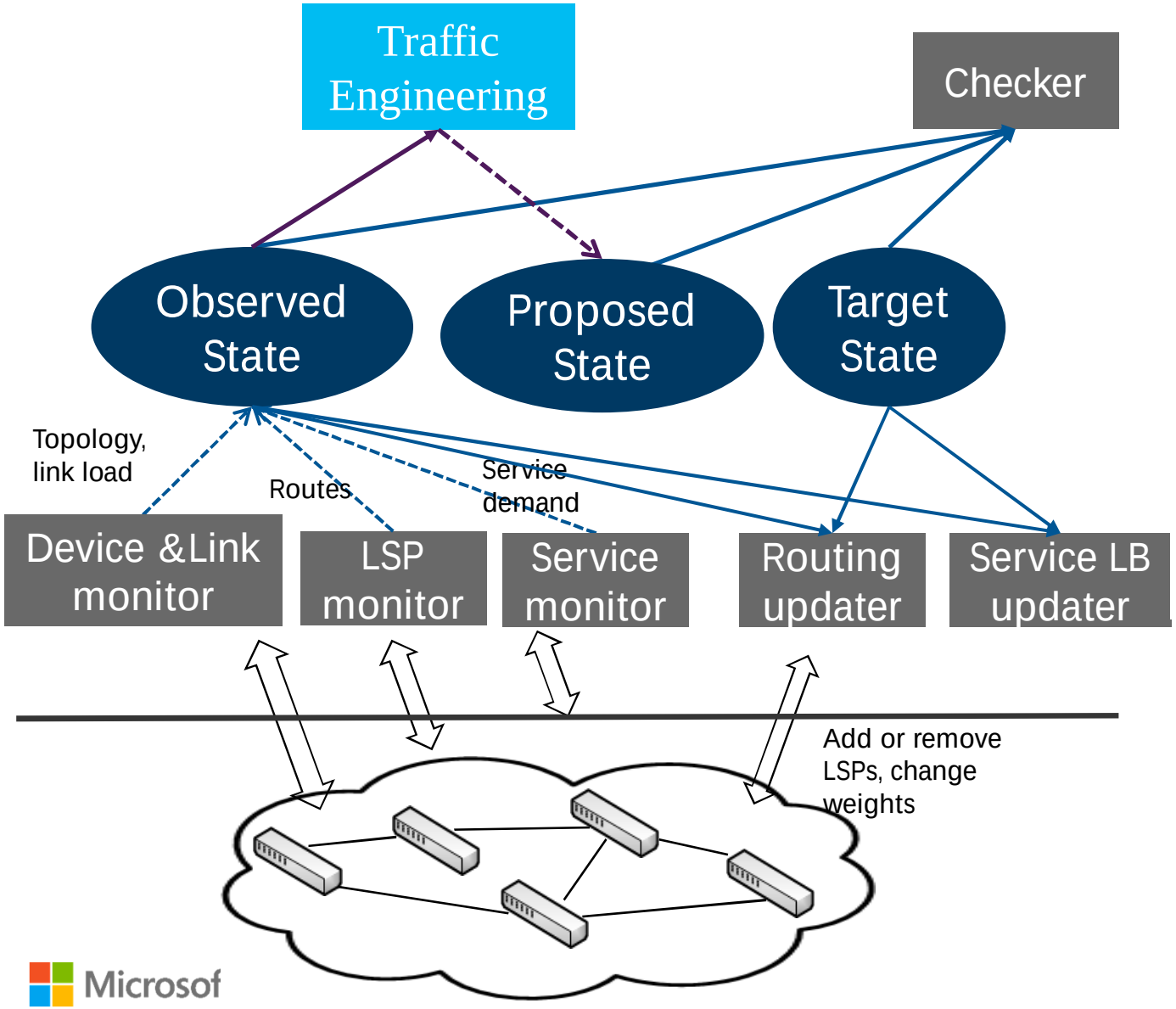


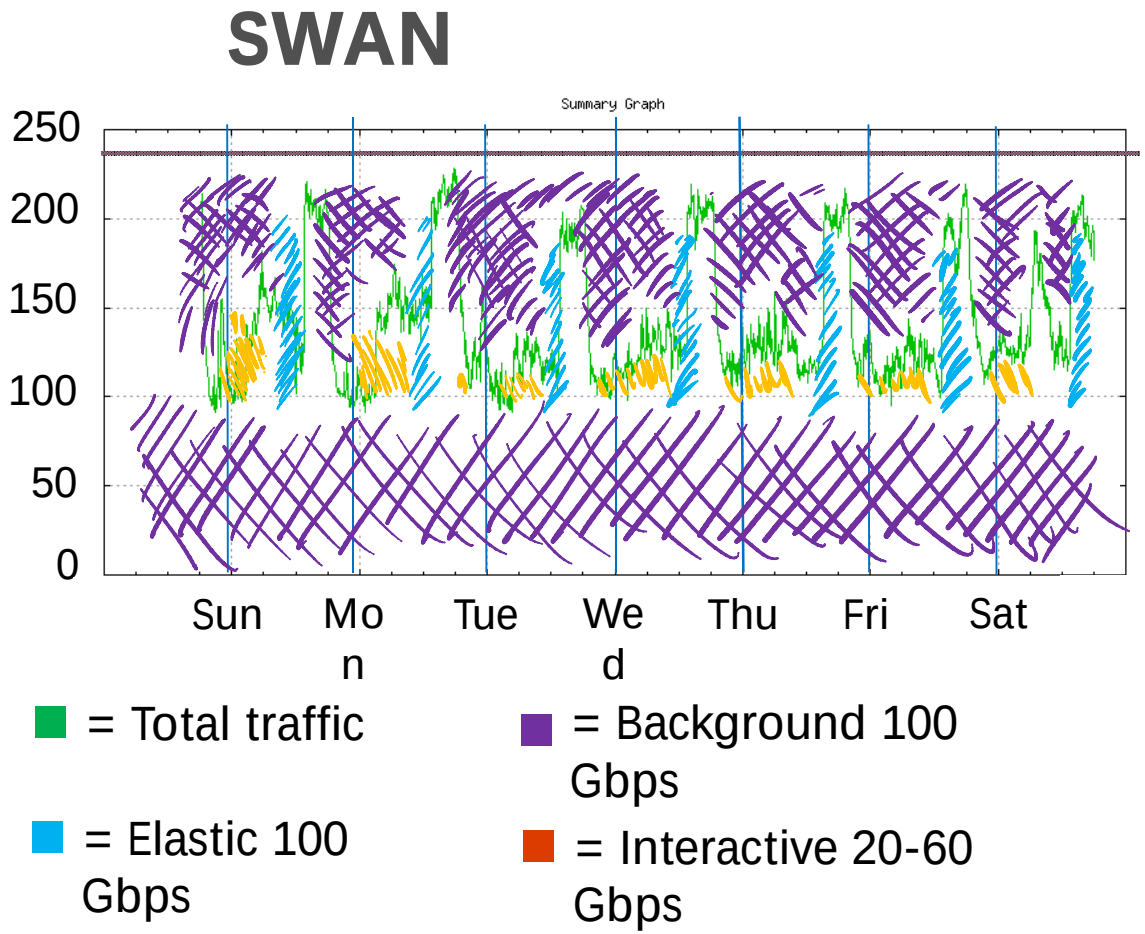




Parity Error in ASIC

App II: Traffic Engineering Towards High Utilization



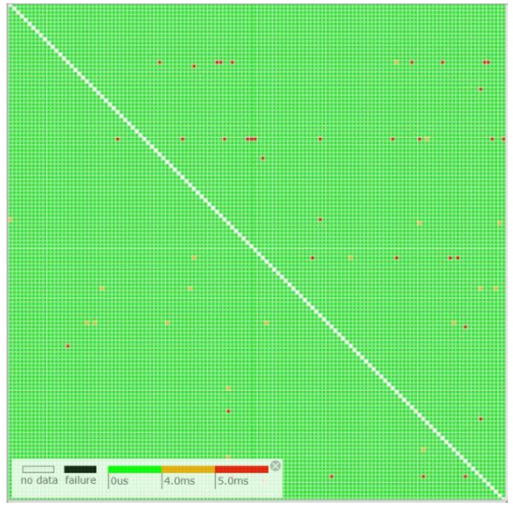


Microsof

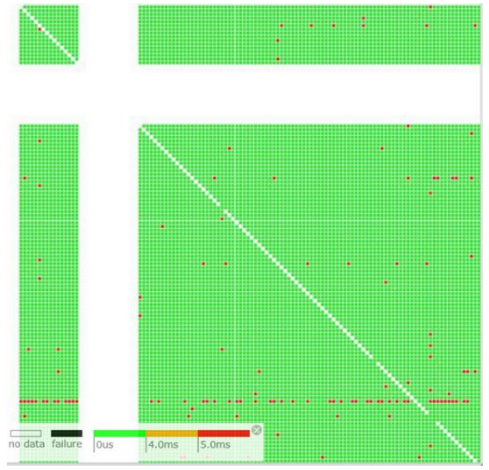
Azure Scale Monitoring – Pingmesh

- Problem: Is it the app or the net explaining app latency issues?
- Solution: Measure the network latency between any two servers
- Full coverage, always-on, brute force
- Running in Microsoft DCs for near 5 years, generating 200+B probes every day

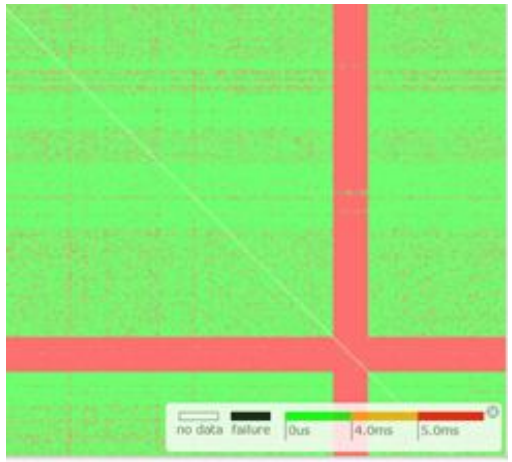
Use high scale cloud computing to monitor cloud network



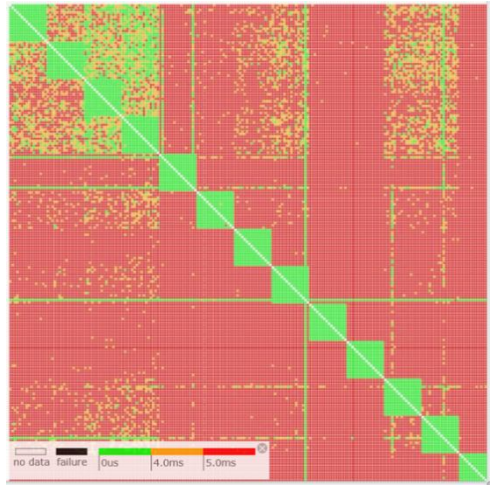
Normal



Podset down



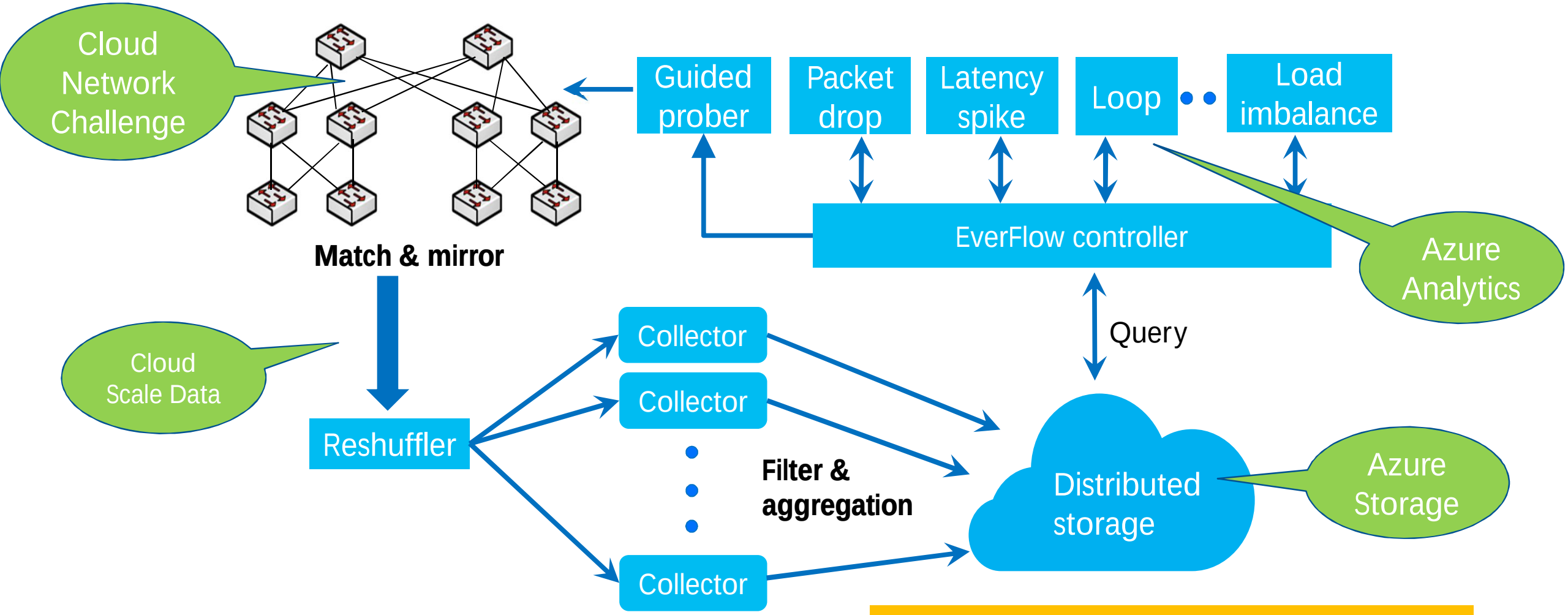
Podset failure



Spine failure

Microsoft

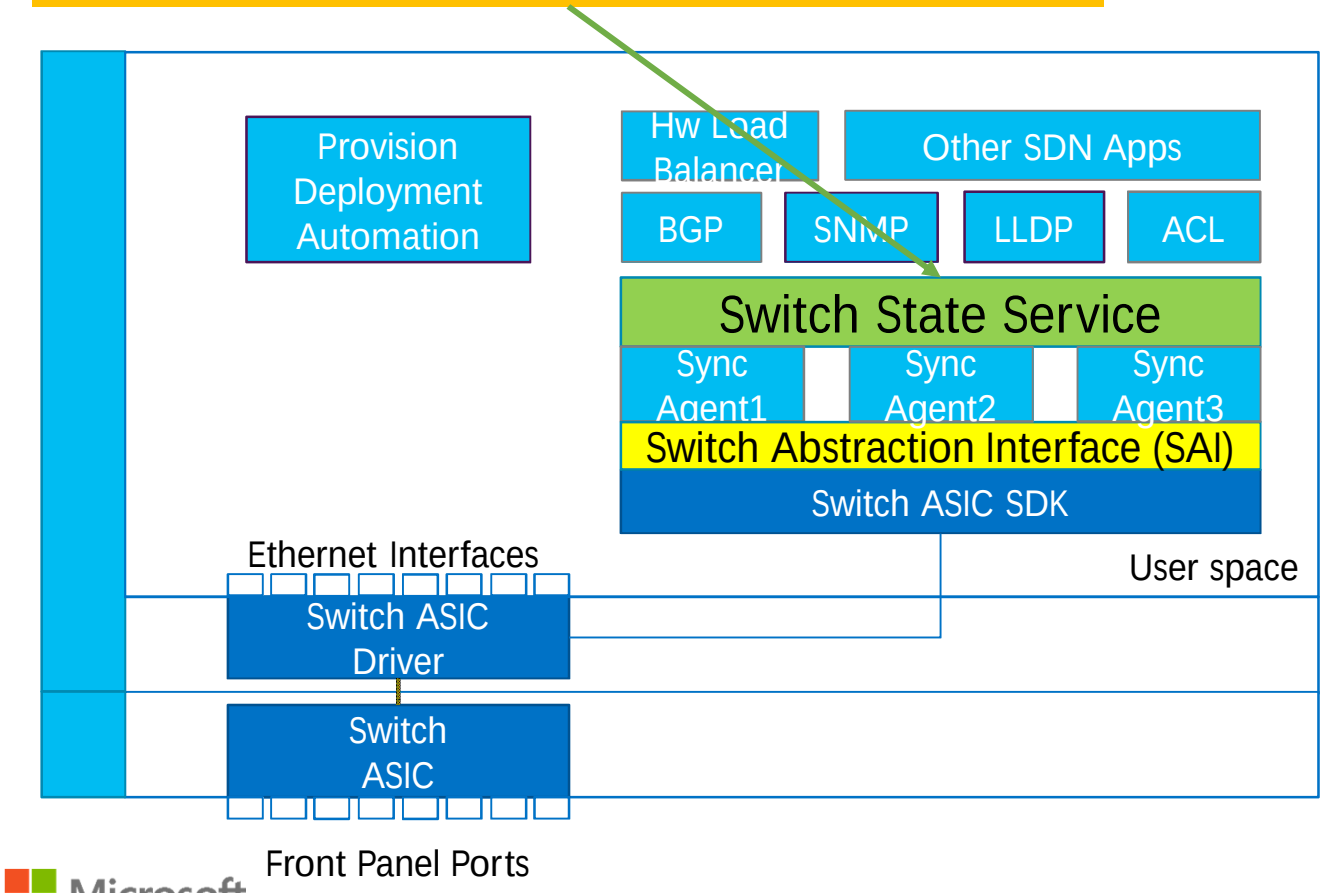
EverFlow: Packet-level Telemetry + Cloud Analytics

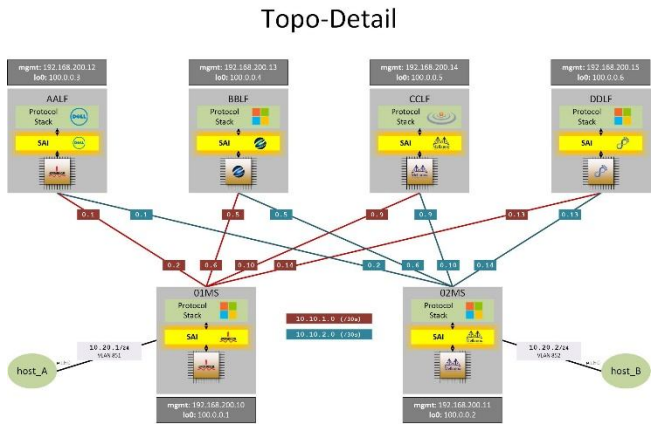


Fast time to pinpoint root cause

Azure Cloud Switch – Open Way to Build Switch OS

- SAI collaboration is industry wide
- SAI simplifies bringing up Azure Cloud Switch (Azure's switch OS) on new ASICS





SAI is on github

Microsoft

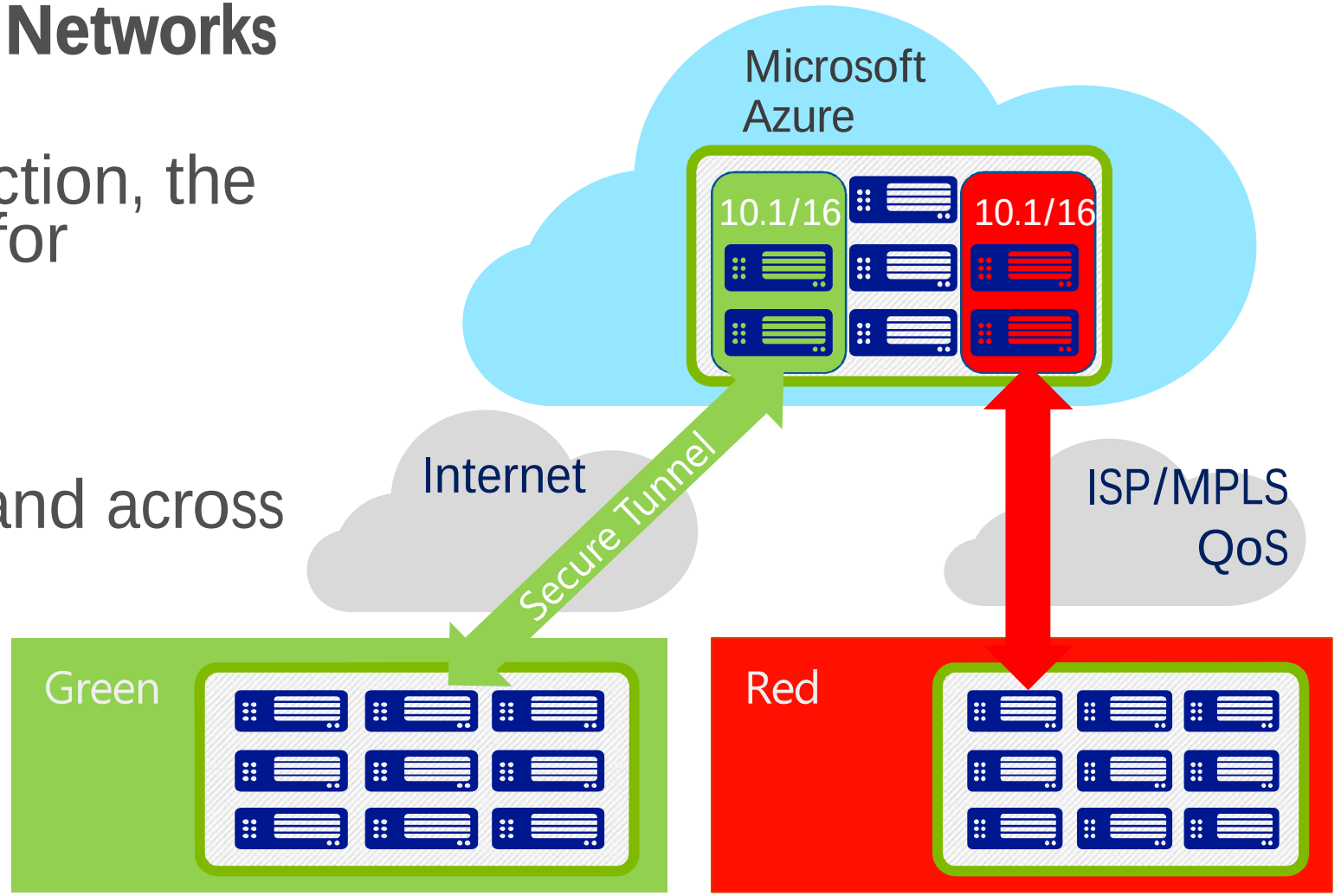
Hyperscale Virtual Networks

Network Virtualization (VNet)

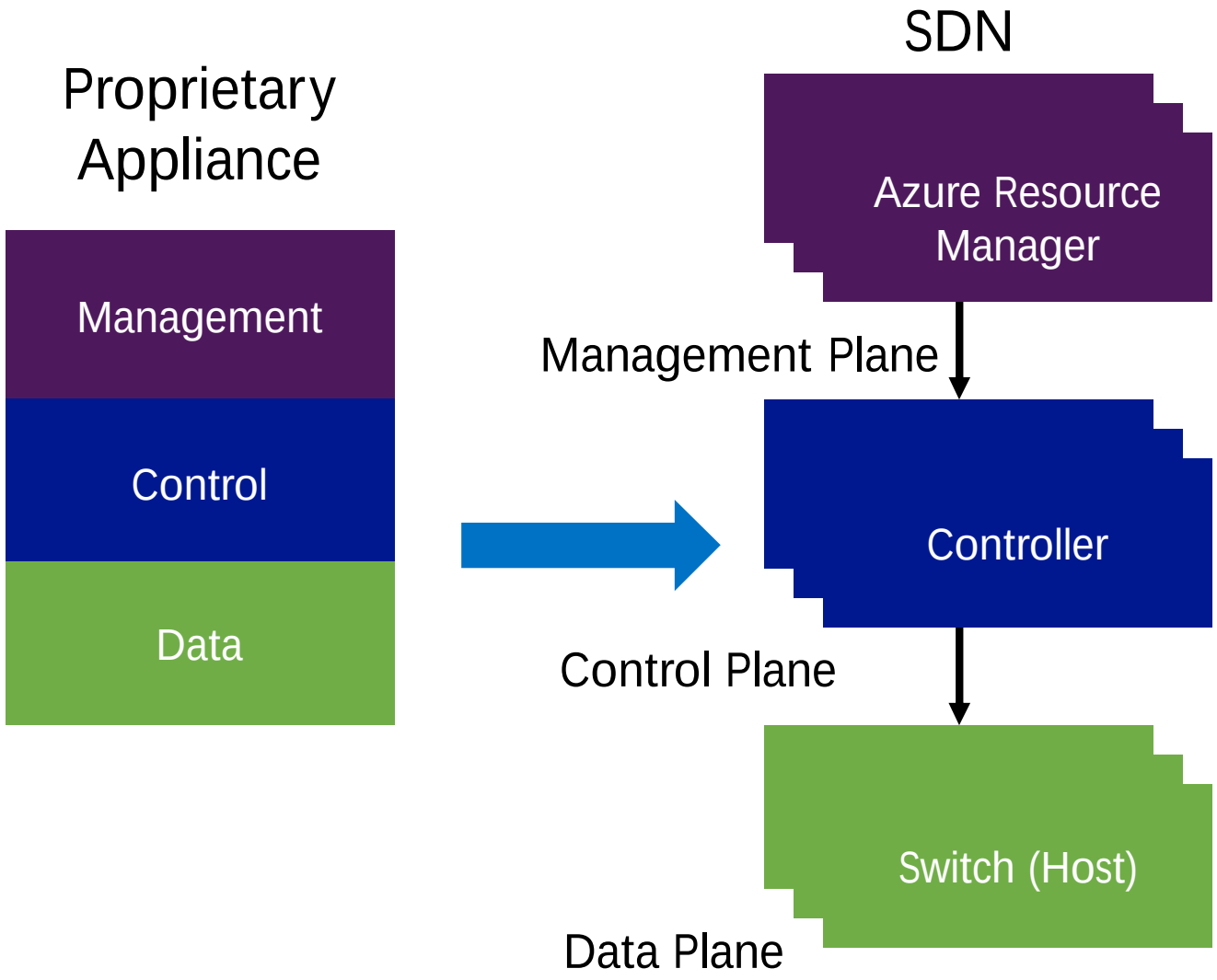
Microsoft Azure Virtual Networks

VNet is the right abstraction, the counterpart of the VM for compute

Efficient and scalable communication within and across VNets



Hyperscale SDN: All Policy is in the Host



Key Challenges for Hyperscale SDN Controllers

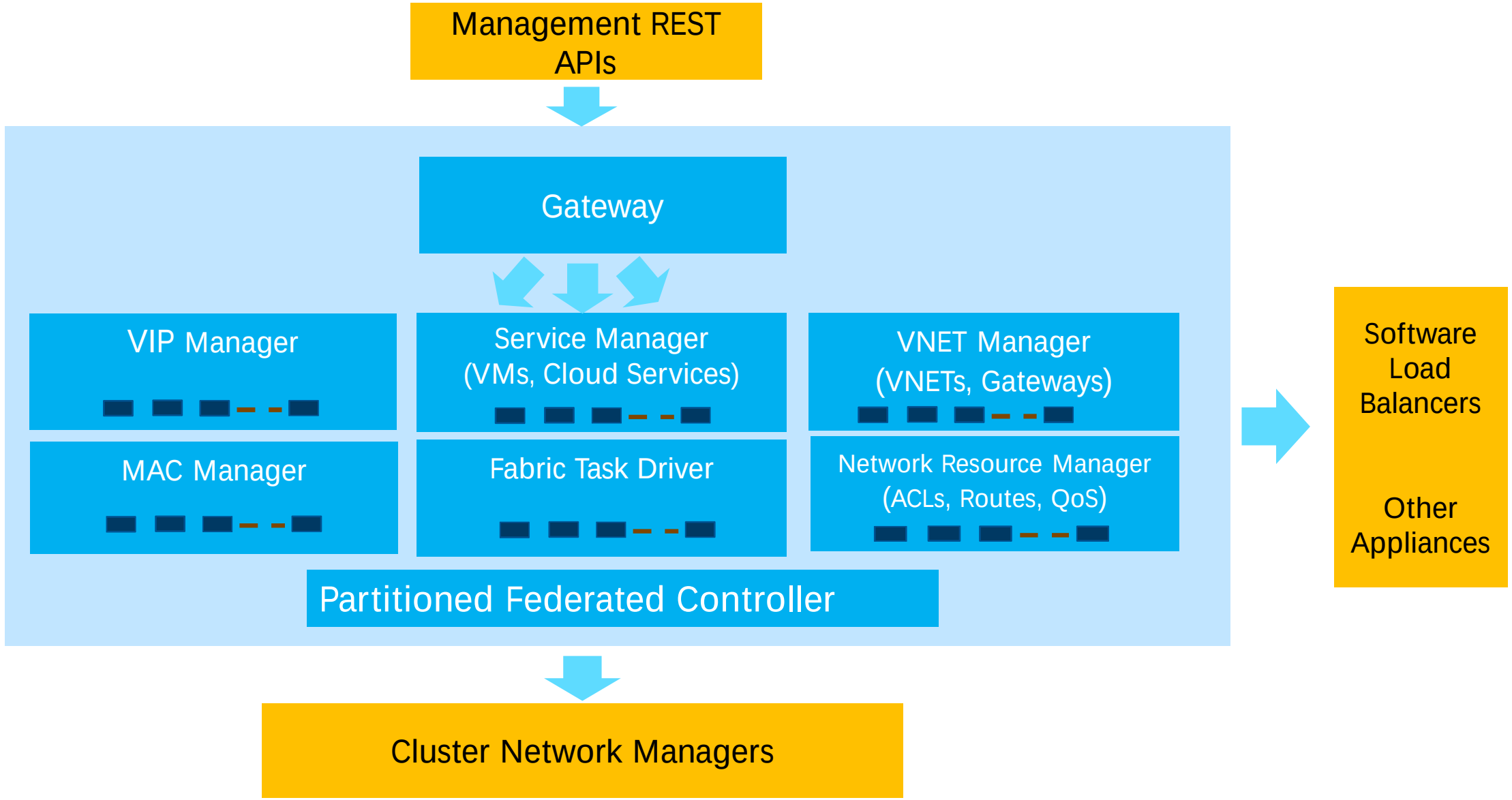
Must scale to 500k+ Hosts in a region

Needs to scale down to small deployments too

Must handle millions of updates per day

Must support frequent updates without downtime

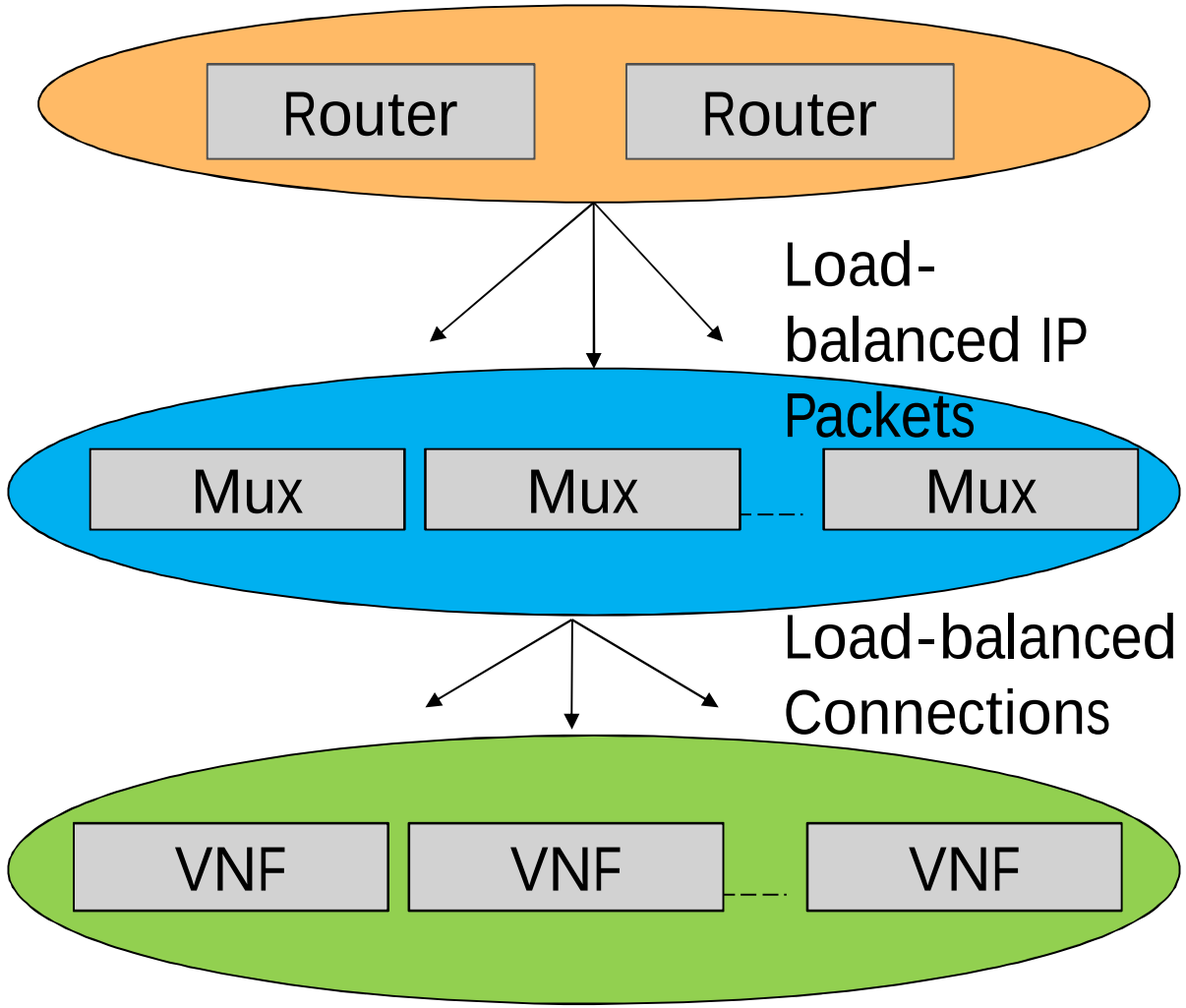
Regional Network Manager Microservices



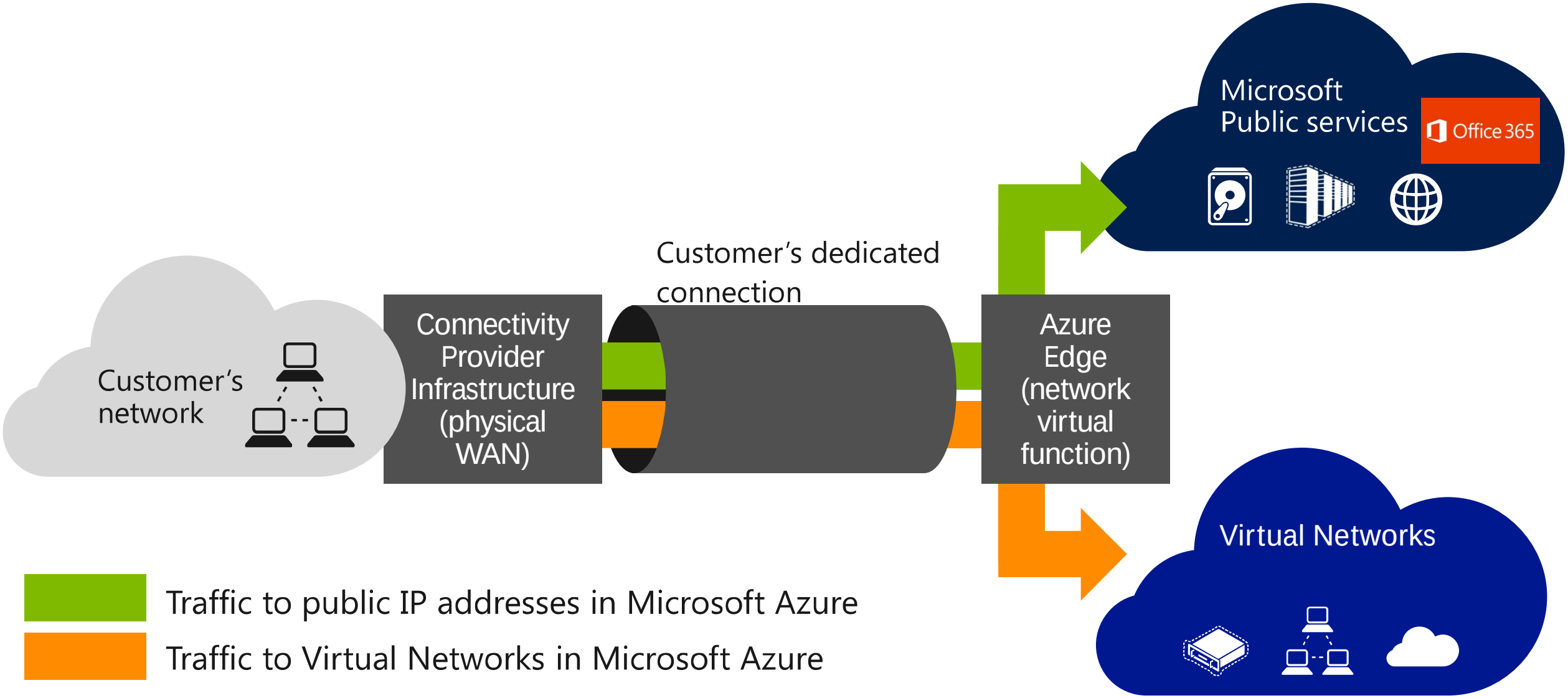
Hyperscale Network Function Virtualization

Azure SLB: Scaling Virtual Network Functions

- Key Idea: Decompose Load Balancing into Tiers to achieve scale-out data plane and centralized control plane
- Tier 1: Distribute packets (Layer 3)
  - Routers ECMP
- Tier 2: Distribute connections (Layer 3-4)
  - Multiplexer or Mux
  - Enable high availability and scale-out
- Tier 3: Virtualized Network Functions (Layer 3-7)
  - Example: Azure VPN, Azure Application Gateway, third-party firewall

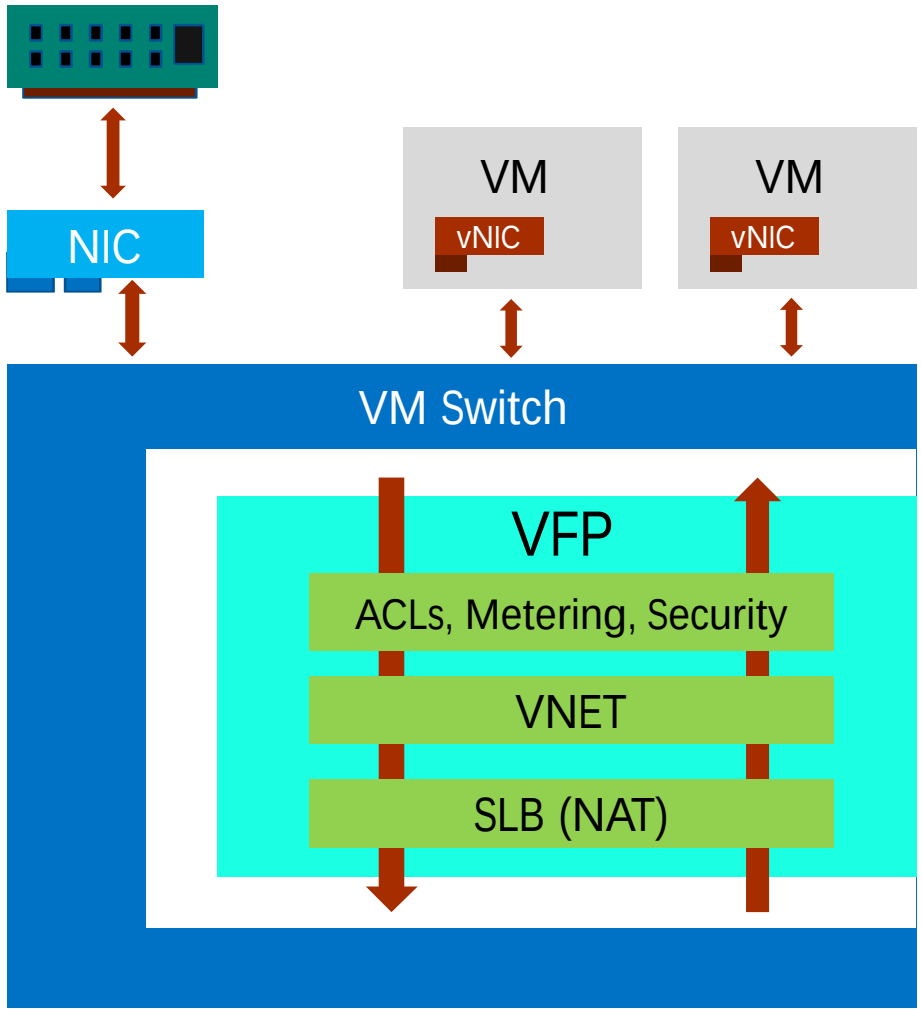


Express Route: Direct Connectivity to the Cloud



Building a Hyperscale Host SDN

Virtual Filtering Platform (VFP)



Acts as a virtual switch inside Hyper-V VMSwitch

Provides core SDN functionality for Azure networking services, including:

- Address Virtualization for VNET
- VIP -> DIP Translation for SLB
- ACLs, Metering, and Security Guards

Uses programmable rule/flow tables to perform per-packet actions

Supports all Azure data plane policy at 40GbE+ with offloads

Coming to private cloud in Windows Server 2016

Flow Tables: the Right Abstraction for the Host

VMSwitch exposes a typed Match-Action-Table API to the controller

- Controllers define policy
- One table per policy

Key insight: Let controller tell switch exactly what to do with which packets

- e.g. encap/decap, rather than trying to use existing abstractions (tunnels, ...)

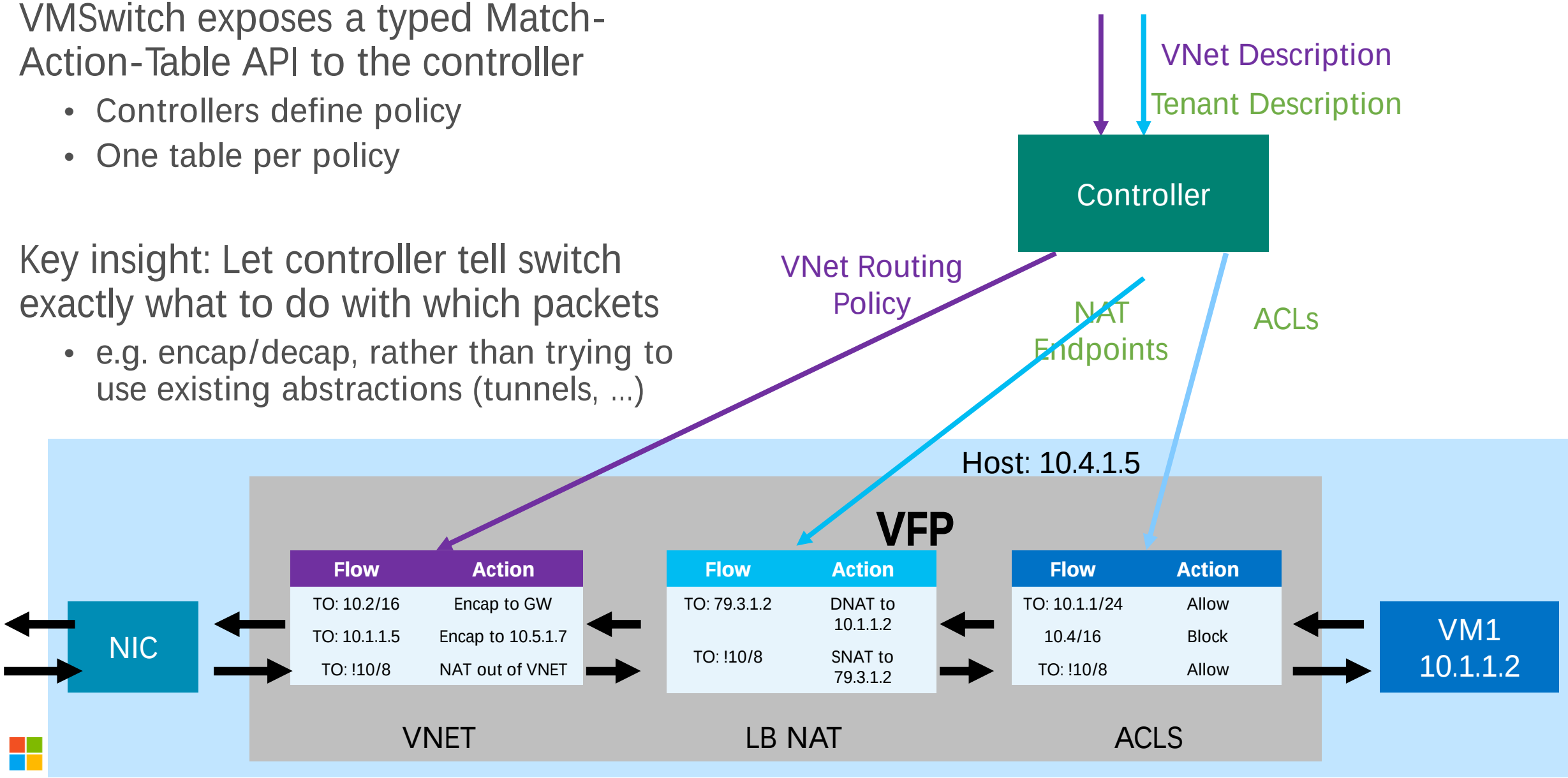
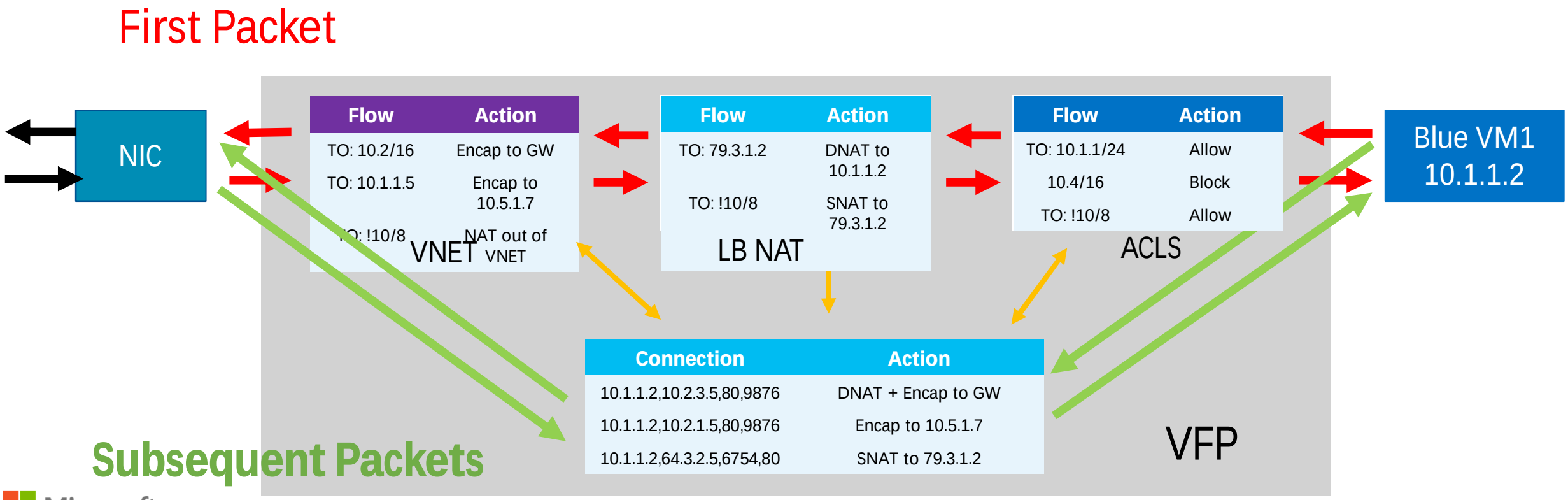
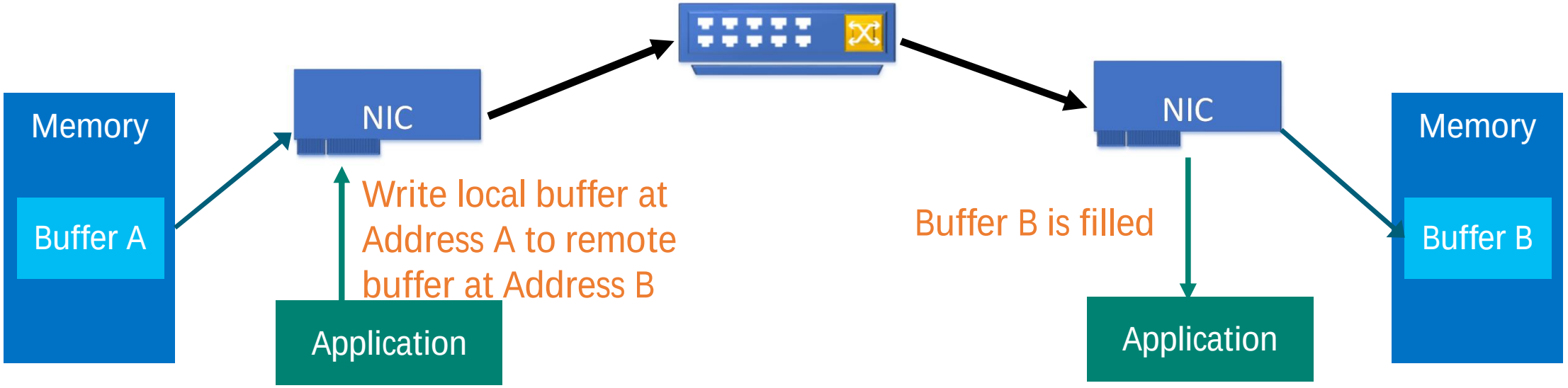


Table Typing/Flow Caching are Critical to Performance

- COGS in the cloud is driven by VM density: 40GbE is here
- First-packet actions can be complex
- Established-flow matches must be typed, predictable, and simple hash lookups



RDMA/RoCEv2 at Scale in Azure



- RDMA addresses high CPU cost and long latency tail of TCP
  - Zero CPU Utilization at 40Gbps
  - µs level E2E latency
- Running RDMA at scale
  - RoCEv2 for RDMA over commodity IP/Ethernet switches
  - Cluster-level RDMA
  - DCQCN for end-to-end congestion control

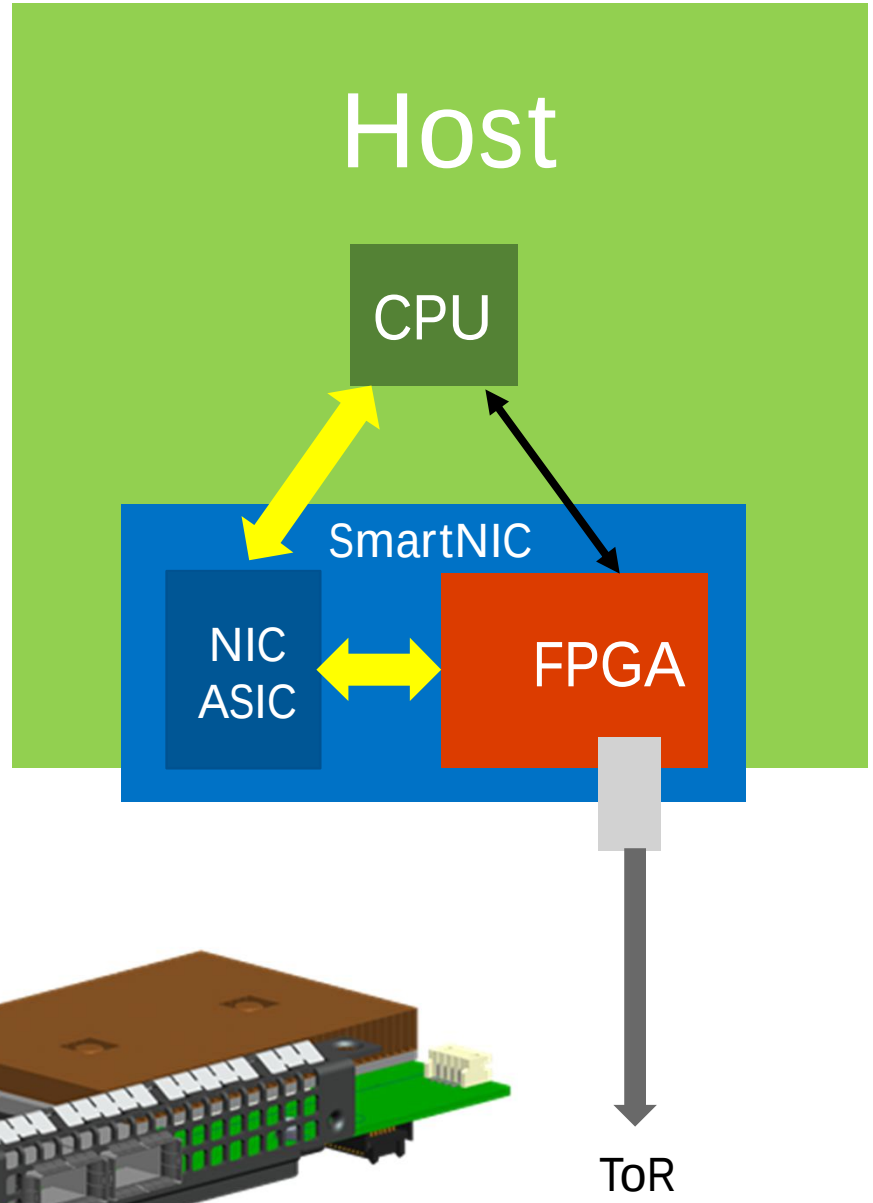
Host SDN Scale Challenges

- Host network is Scaling Up: 1G → 10G → 40G → 50G → 100G
  - The driver is VM density (more VMs per host), reducing COGs
  - Need the performance of hardware to implement policy without CPU
- Need to support new scenarios: BYO IP, BYO Topology, BYO Appliance
  - We are always pushing richer semantics to virtual networks
  - Need the programmability of software to be agile and future-proof

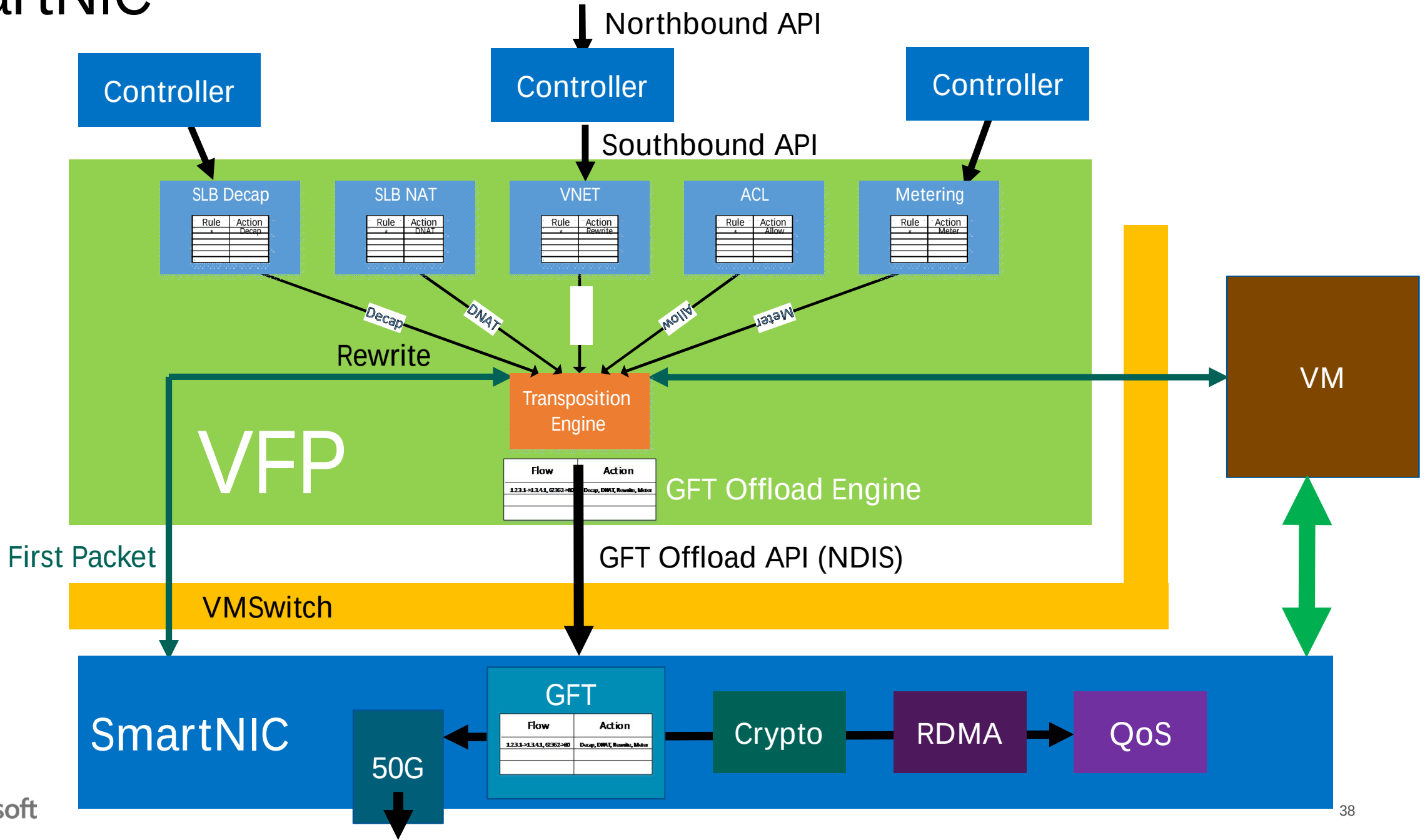
How do we get the performance of hardware with programmability of software?

Azure SmartNIC

- Use an FPGA for reconfigurable functions
  - FPGAs are already used in Bing (Catapult)
  - Roll out Hardware as we do software
- Programmed using Generic Flow Tables (GFT)
  - Language for programming SDN to hardware
  - Uses connections and structured actions as primitives
- SmartNIC can also do Crypto, QoS, storage acceleration, and more…



SmartNIC


Northbound API
Controller
Controller
Controller
Southbound API
SLB Decap
SLB NAT
VNET
ACL
Metering
Rule
Action
Decap
DNAT
Rewrite
Allow
Meter
Rewrite
Transposition Engine
VFP
Flow
Action
GFT Offload Engine
VM
First Packet
GFT Offload API (NDIS)
VMSwitch
SmartNIC
GFT
Flow
Action
50G
Crypto
RDMA
QoS

Azure SmartNIC

Career Advice

Cloud

Software → enables leverage and agility

Even for hardware people

Time → Hard systems problems take time

With the right team and right project, its worth it

Usage and its measurement → oxygen for ideas

Foundation and proof that the innovation matters

Ship & iterate quickly → continuous improvements

Make mistakes early, iterate, and ship often