

Delivering High Quality Internet Services



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25 Nov 2019

Delivering High Quality Internet Services

1

Network
Building
Blocks

2

The
Internet

3

Protect
The Internet

4

SDN



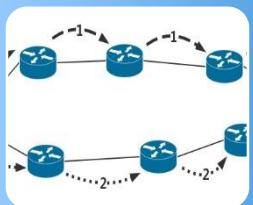
Applications/Contents

- Video/Voice
- Messaging, Web, Games



Autonomous System (2 or 4 bytes)

- Public ASN (1 – 23455, 23457 – 64495)
- Private ASN (64512 – 65534)



Routing Protocols

- EGP (EBGP, IBGP)
- IGP (OSPF, ISIS)



Public IP Address

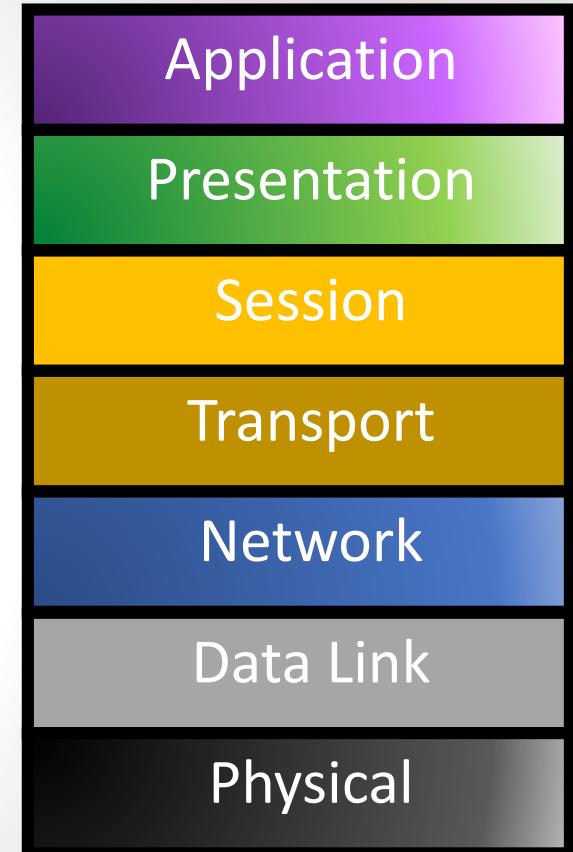
- IPv4 (32-bit, ~4.3 billion addresses)
- IPv6 (128-bit, $\sim 3.4 \times 10^{38}$ addresses)



Physical Links

- Ethernet

Open Systems Interconnection (OSI) model





Public IP Address

- IPv4
- IPv6

Dual stack

There are five
Regional Internet Registry (RIR)

American Registry for
Internet Numbers (ARIN)

for the United
States, Canada,
several part of the
Caribbean region, and
Antarctica.

Latin America and
Caribbean Network
Information Centre
(LACNIC) for Latin
America and parts of
the Caribbean region

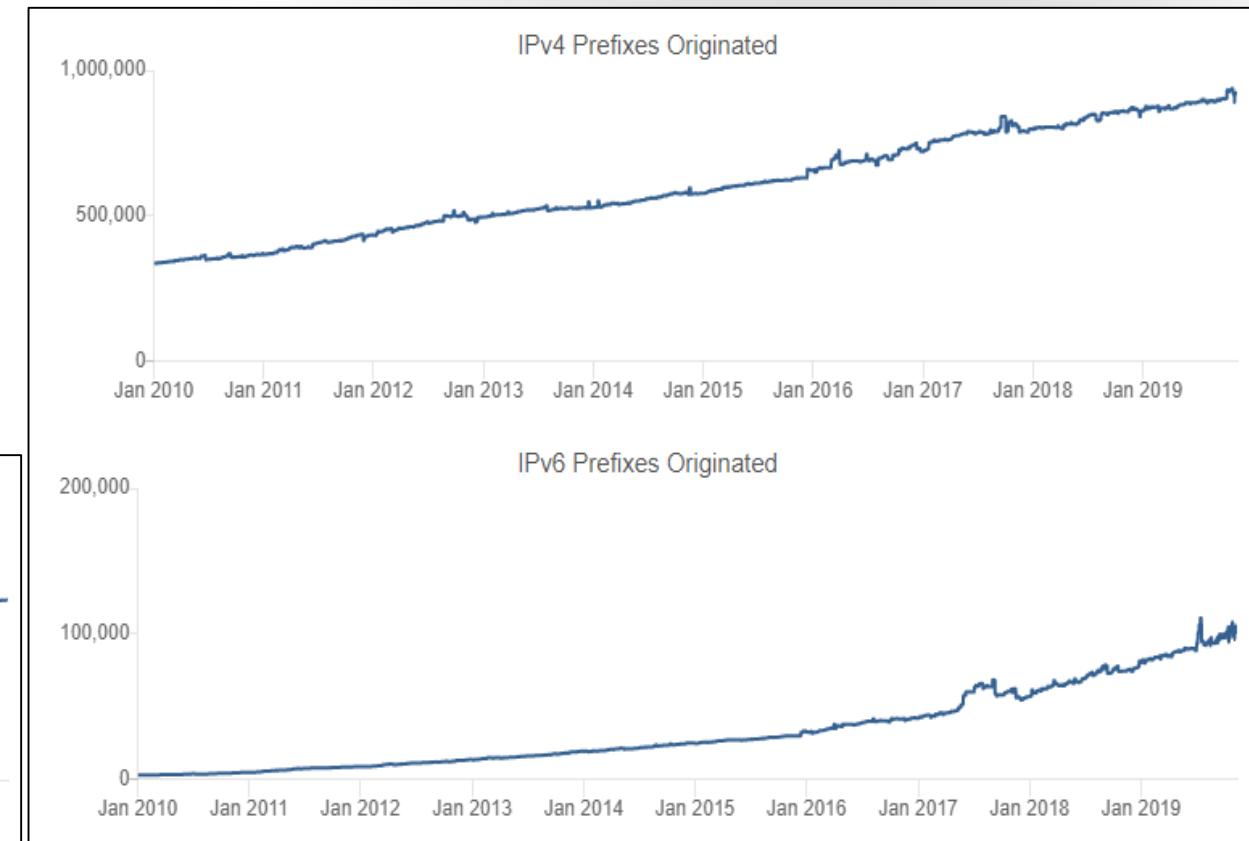
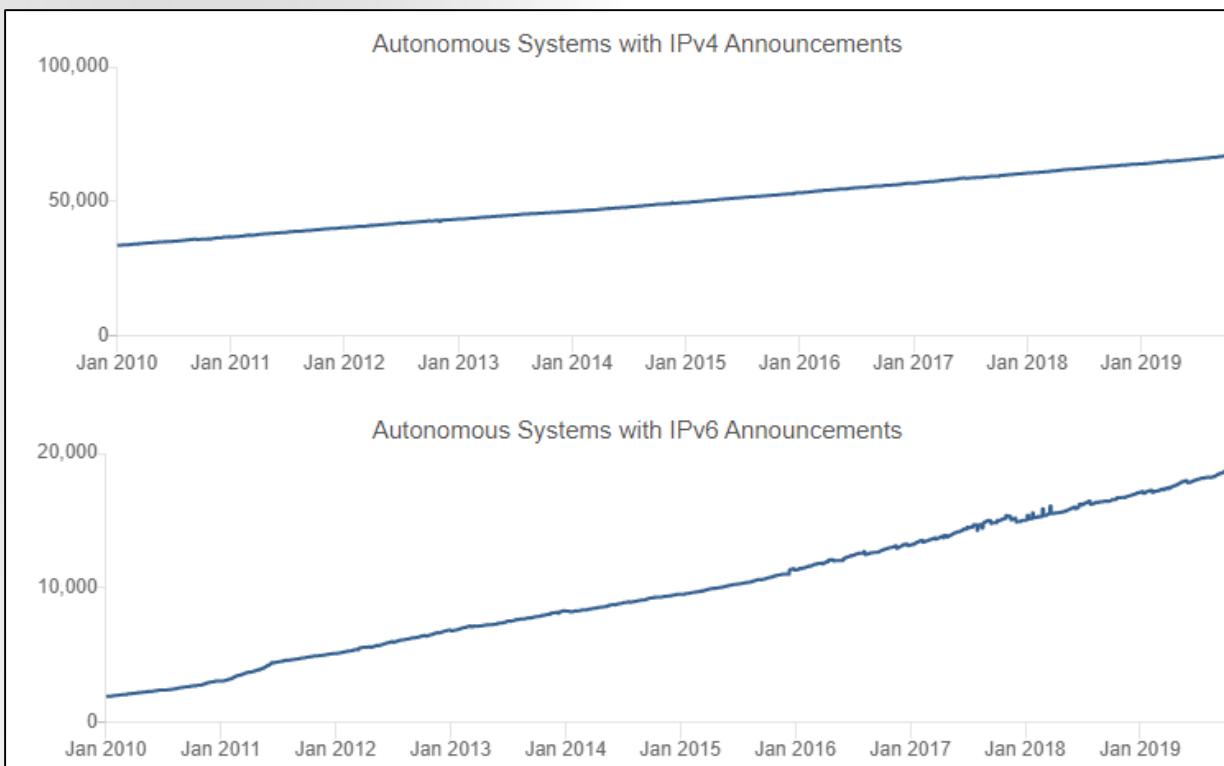


African Network Information
Center (AFRINIC) for Africa

Asia-Pacific
Network Inform-
ation Centre
(APNIC) for
Asia, Australia,
New Zealand, and
neighboring countries

Public IP Address and AS Number

Autonomous System (AS) is a collection of IP prefixes under the control of one single administrative domain

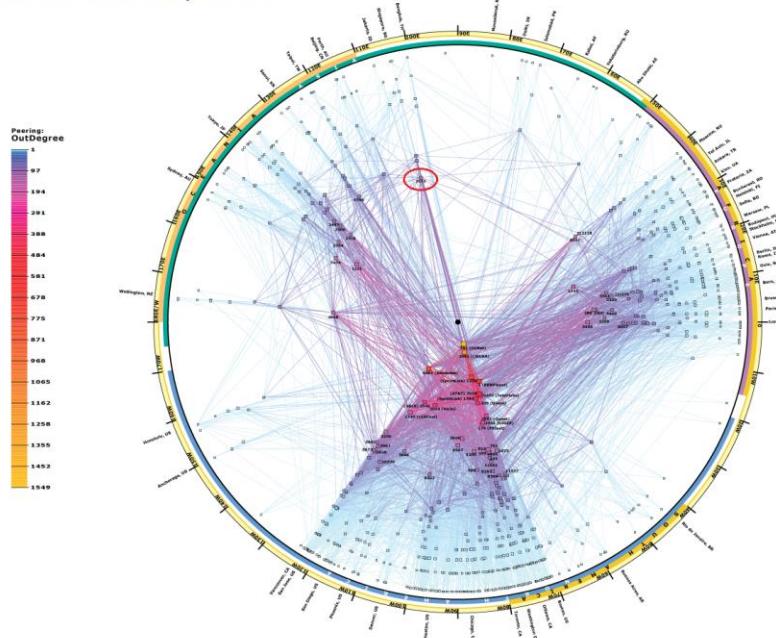


*Source: Center for Applied Internet Data Analysis (CAIDA)

Internet Topology Maps by CAIDA

CAIDA's IPv4 AS Core AS-level INTERNET GRAPH

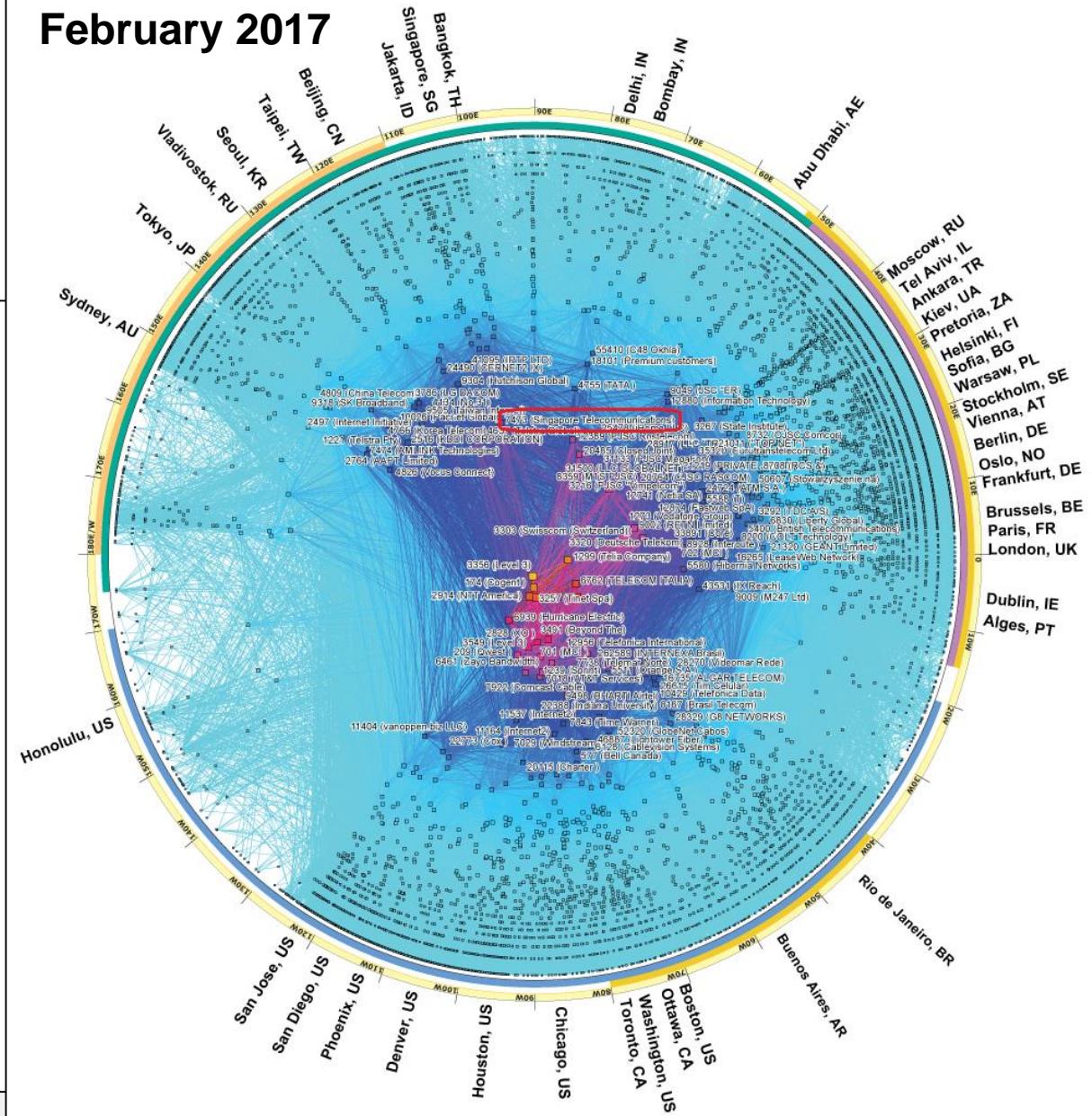
Skitter January 2000



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*Source: Center for Applied Internet Data Analysis (CAIDA)

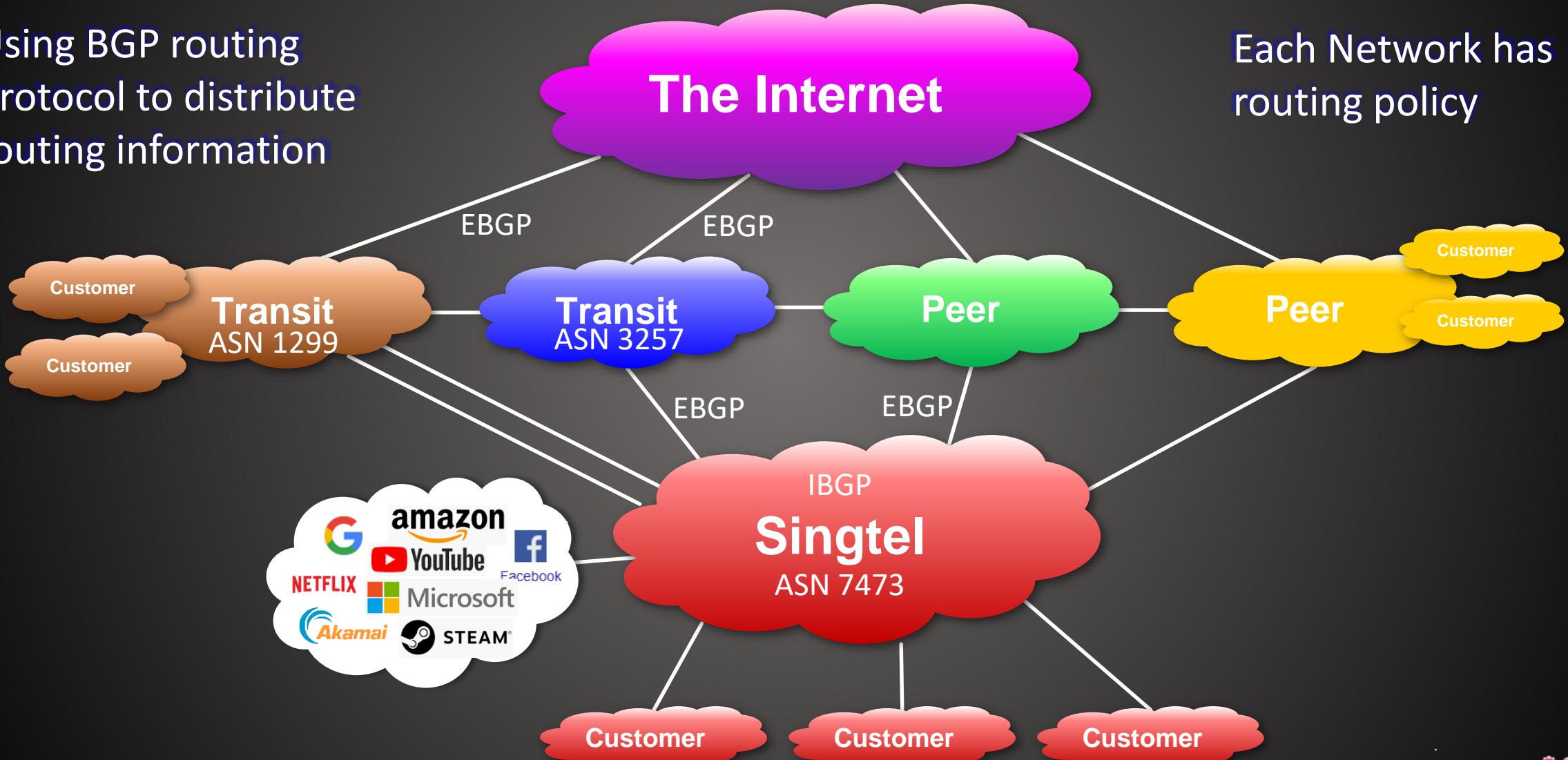
February 2017



Internet Interconnections

Using BGP routing protocol to distribute routing information

Each Network has routing policy



Border Gateway Protocol (BGP)

- BGP is an exterior gateway routing protocol (EGP)
- Allows each network to signal to other networks what destinations (prefixes) they can reach
- BGP sessions are established by manual configuration
- TCP port 179
- The current version is version 4 (BGP4)
- BGP4 was published as RFC 4271 in 2006
- BGP4 has been in use on the Internet since 1994
- IPv6 BGP was first defined in RFC 1883 in 1995

How BGP Works

- BGP learns multiple paths to each route
- BGP Path Selection: BGP selects the best path
- The best path is used to forward traffic
- Only the best path is sent along to other BGP neighbours
- BGP attributes: e.g. for Traffic Engineering, Automation
- BGP Routing Policies: e.g. for inbound vs outbound traffic

BGP Path Selection

1. Validity
2. Reachability
3. Lowest routing protocol preference
4. Higher Local Preference
5. Shortest AS path length
6. Lowest MED
7. Lowest IGP metric
8. Lowest Router-ID

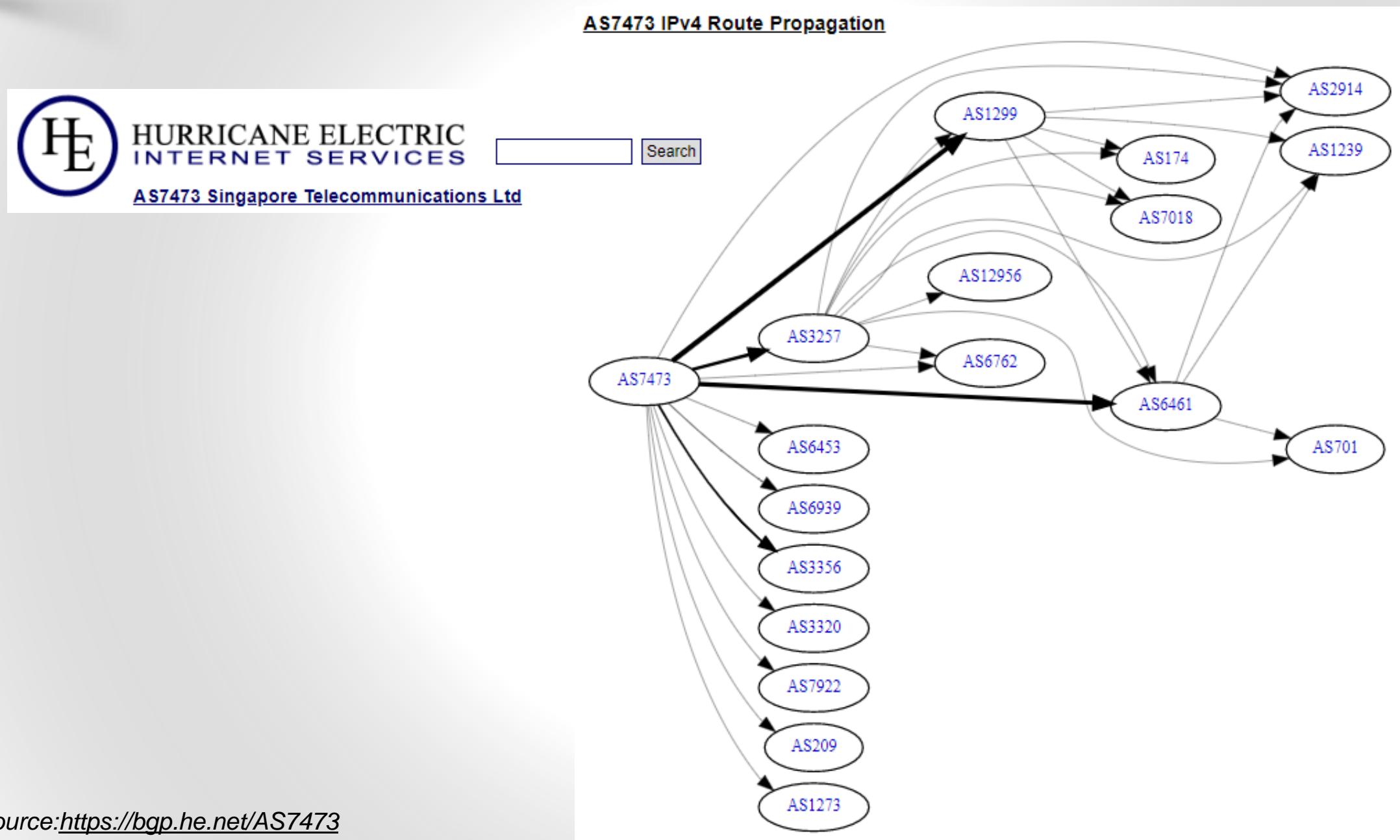
What is Routing Policy?

- Description of relationship between AS Numbers
- Who are my external BGP peers
- Registered on IRR (Internet Routing Registry) such as RADB, PeeringDB or APNIC
- Purpose: documentations, configurations

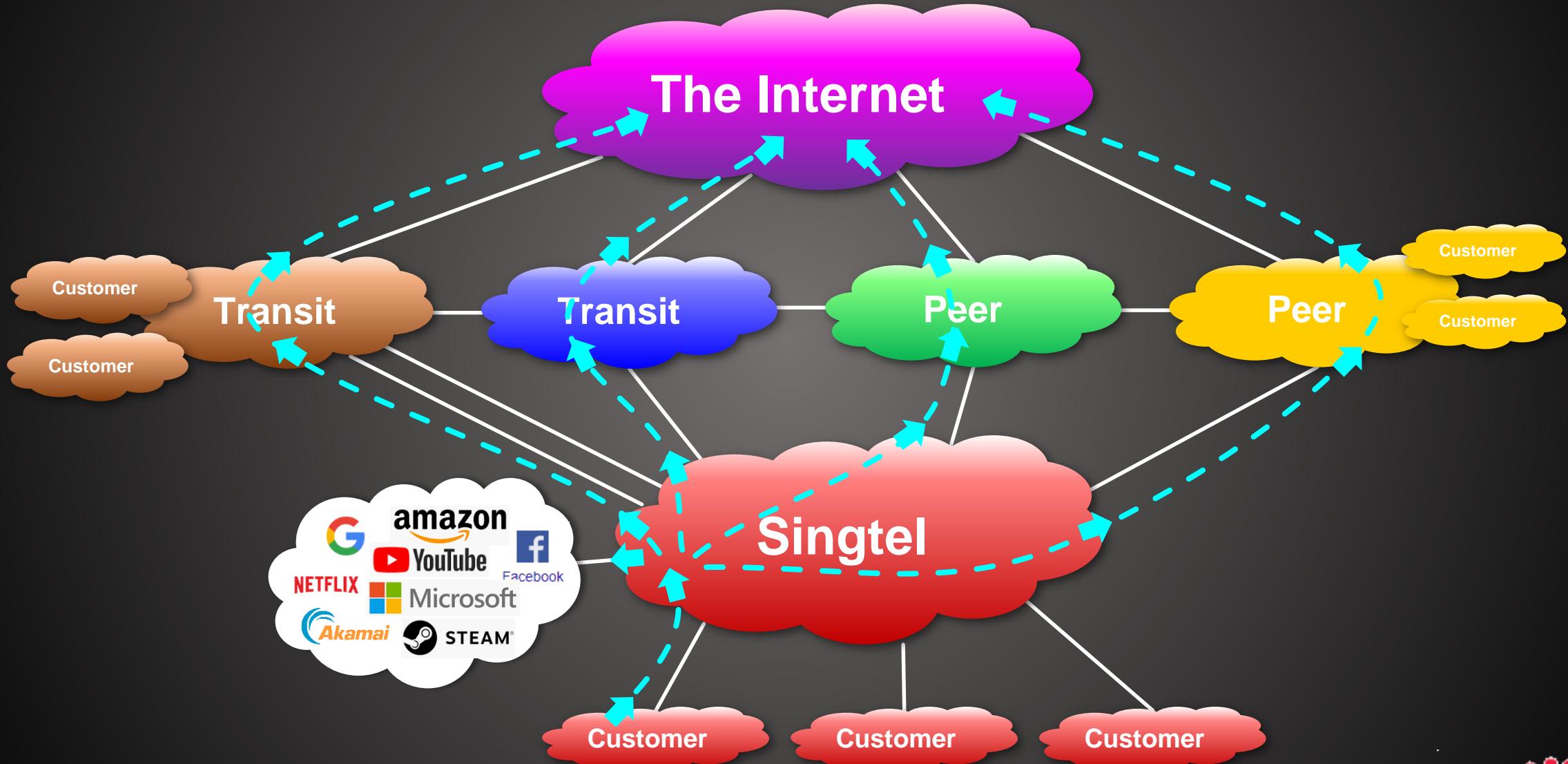
Routing Policy

```
aut-num: AS7473
as-name: SINGTEL-IX
descr: SINGTEL-IX
          Singapore Telecommunications
          Singapore Telecom InterNet Exchange
import: from AS1299 accept ANY AND NOT ({0.0.0.0/0})
import: from AS3257 accept ANY AND NOT ({0.0.0.0/0})
export: to AS-STIX announce ANY AND NOT ({0.0.0.0/0})
admin-c: SAK609
tech-c: SAK609
remarks: Send peering request to g-stixpeer@singtel.com
notify: g-stixnoc@singtel.com
mnt-by: MAINT-AS7473
changed: leonkoh@singtel.com 20160331 #07:35:00Z
source: RADB
```

BGP network map tools



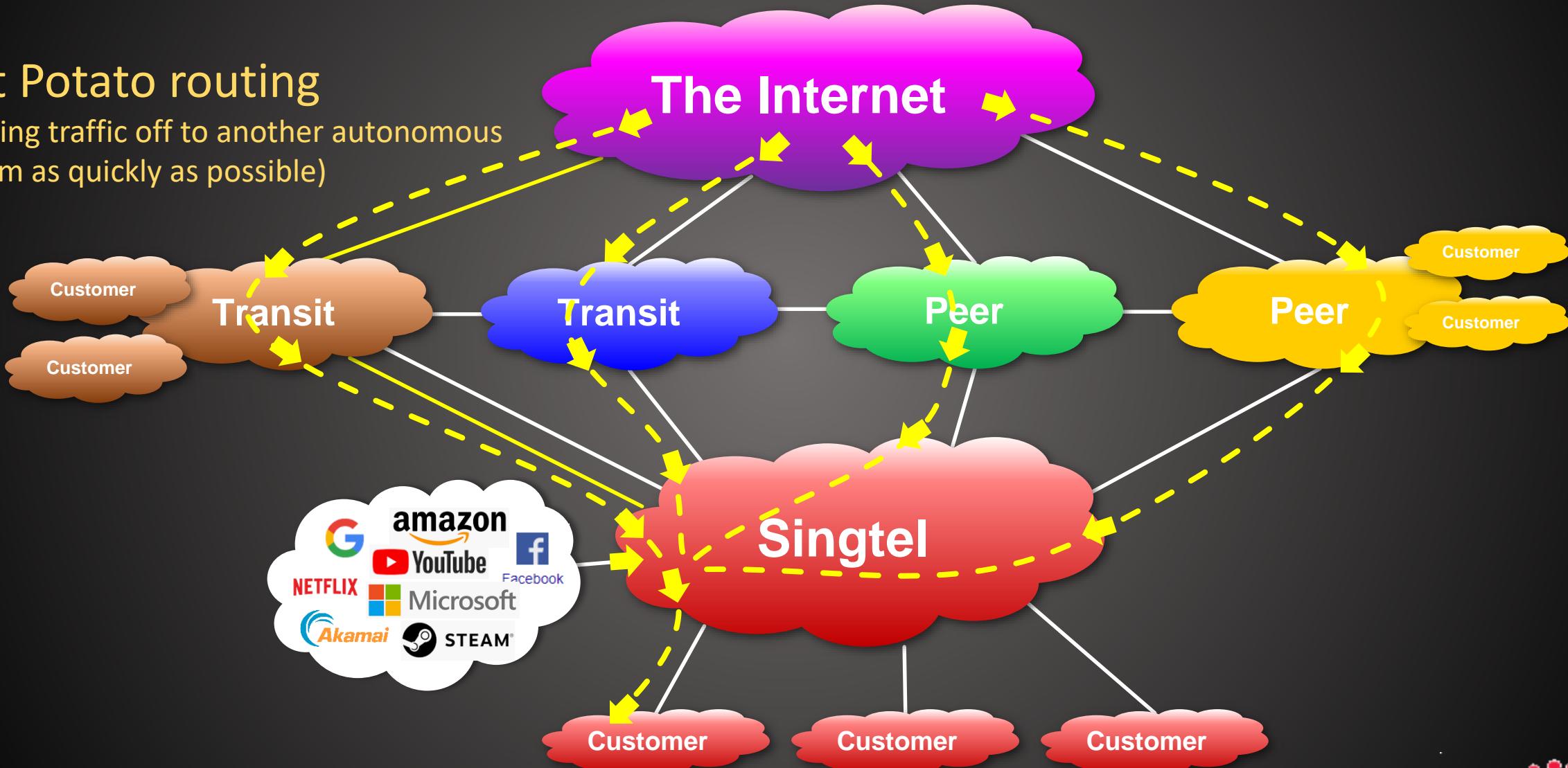
BGP Routes Propagation



Traffic Forwarding

Hot Potato routing

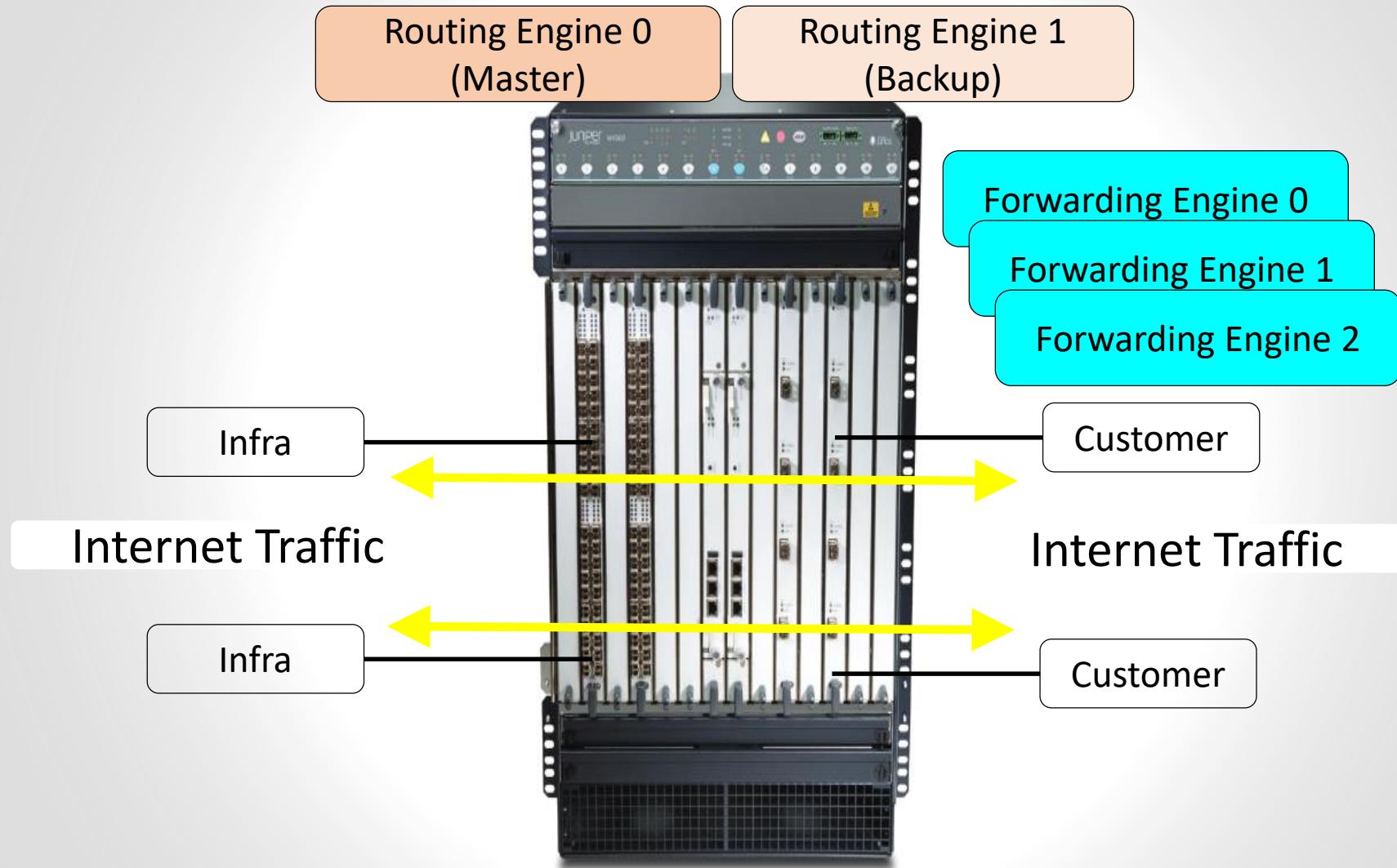
(passing traffic off to another autonomous system as quickly as possible)



Routing vs Forwarding

- ❖ Routing: how reachability of the destination is shared
 - A router may learn multiple paths to one destination
 - Occurs on the control plane (Routing Engine)
 - Stored on Routing Information Base (RIB)
- ❖ Forwarding: sending out packets from input interface to output interface
 - Occurs on Forwarding Engine
 - Only the best path stored on Forwarding Information Base (FIB)

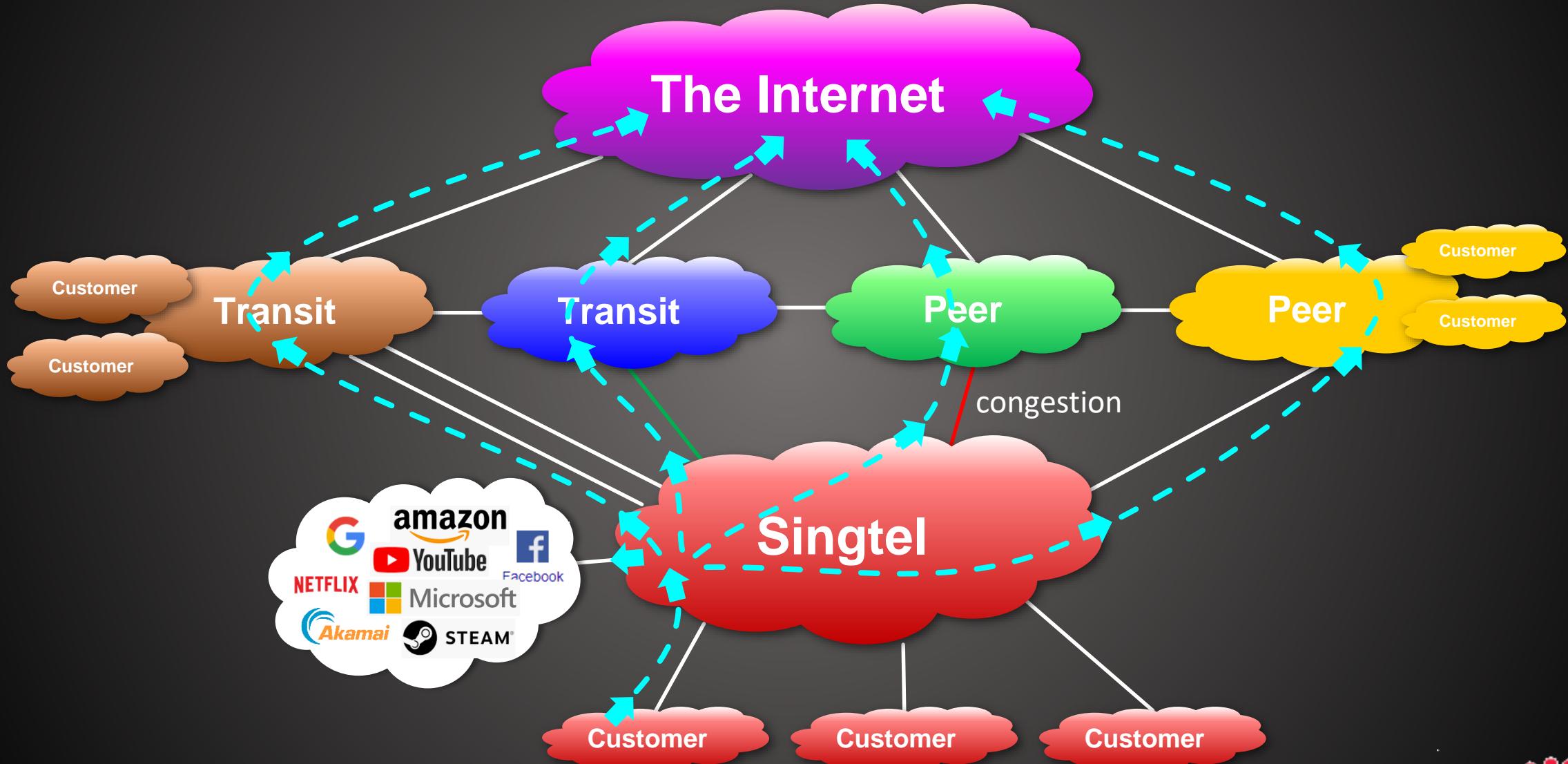
Internet Router



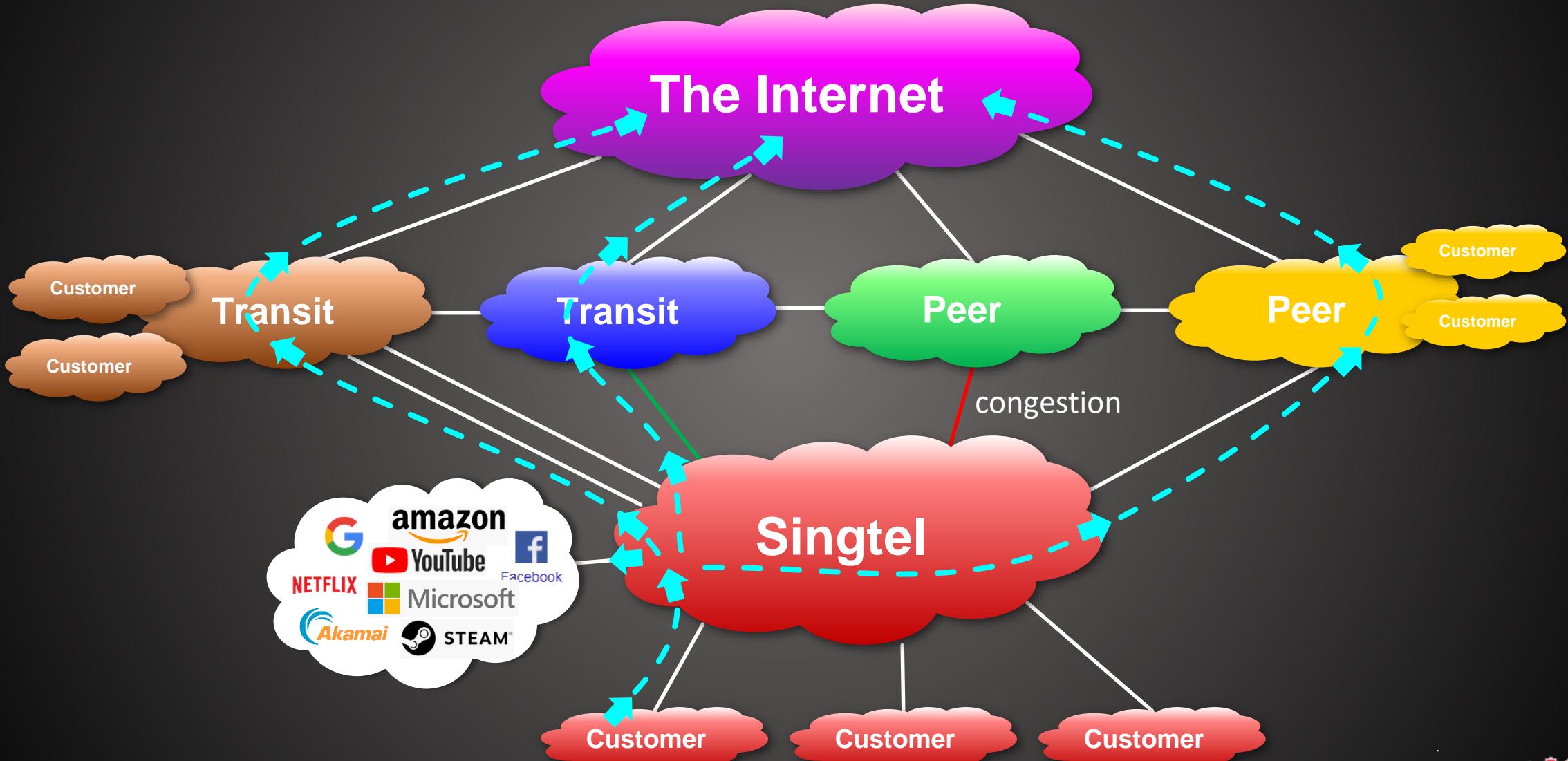
Traffic Engineering

- Manage infra capacity
- Traffic Load sharing
- Ensure service quality (latency, SLA/SLG)
- Manage impact during network changes
- Recover from failures
- Manage service cost

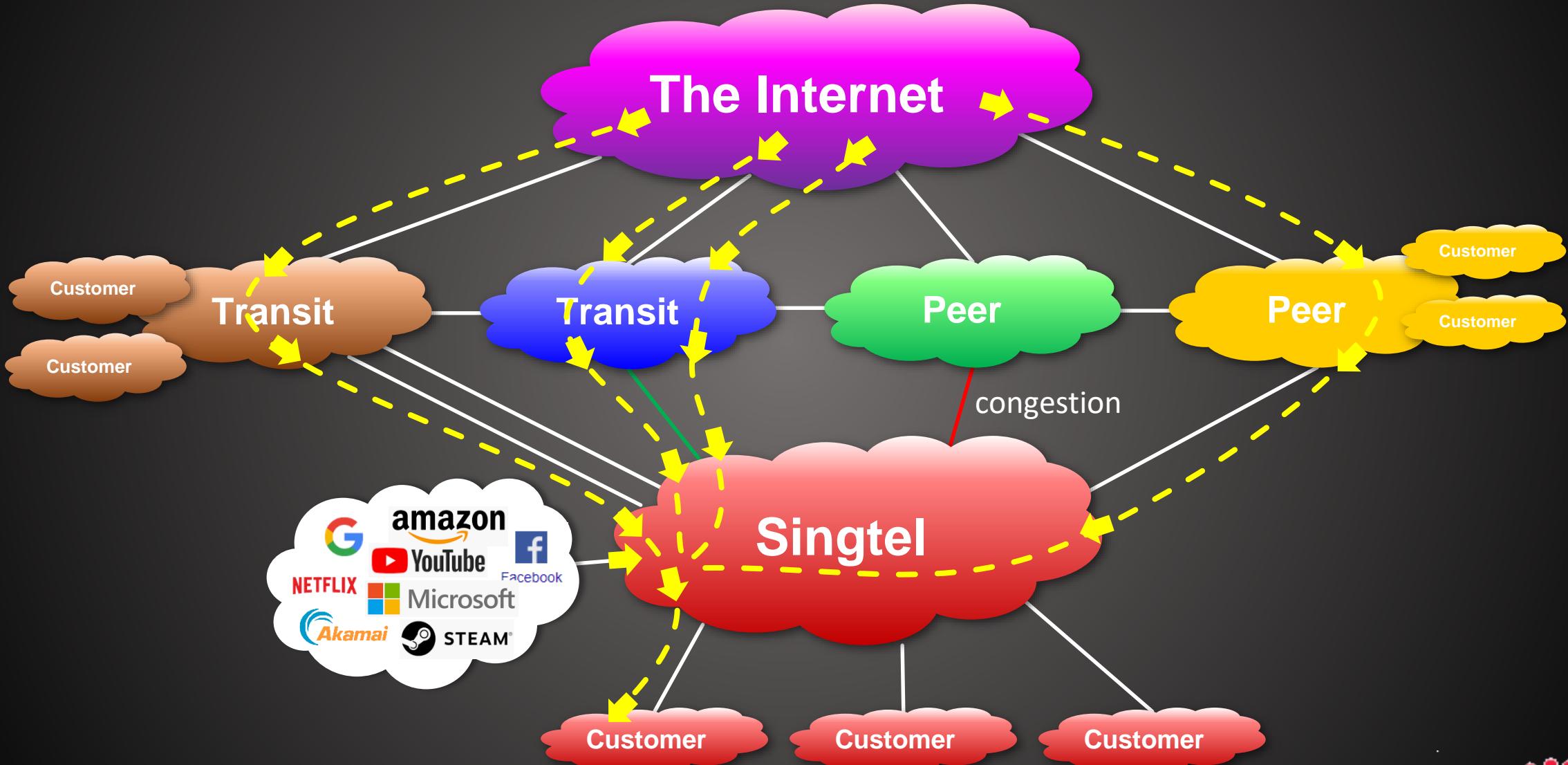
Traffic Engineering - Routes Propagation



Traffic Engineering - Routes Propagation



Traffic Engineering - Traffic Forwarding



Traffic Engineering and Automation

- Traffic and management data: netflow, snmp, syslog
- Routing Policies, flow analysis, correlation, cost
- EPE: Egress Peering Engineering
- IPE: Ingress Peering Engineering
- Tools: Juniper, Cisco, Nokia, Huawei, open source
- Network Programmability -> SDN

Internet Performance

- RTT Latency (millisecond, ms)
- Packet Loss (packets/second, pps)
- Throughput (bits/second, bps)

$$\text{Throughput} \leq \frac{\text{RWIN}}{\text{RTT}}$$

Higher throughput by using multiple TCP streams

- ❖ TCP throughput (single TCP stream)
 - RWIN is the TCP Receive Window (~ memory allocation)
 - RTT is the round-trip time for the path (latency)

Internet Performance - Speedtest

Fastest Countries for Fixed Broadband Internet

Speedtest Global Index™ | Based on Mean Download Speed

Rank	July 2018	July 2019
1	Singapore	Singapore
2	Hong Kong (SAR)	South Korea
3	Romania	Taiwan
4	South Korea	Hong Kong (SAR)
5	United States	Romania
6	Hungary	Monaco
7	Switzerland	Andorra
8	Luxembourg	United States
9	Macau (SAR)	Switzerland
10	Spain	Macau (SAR)



denial-of-service attack (DoS attack)

- It is a cyber-attack
- Makes a machine or network resource unavailable
- Disrupting services of a server or application
- Flooding server with requests to overload systems
- Prevents some or all legitimate requests
- distributed denial-of-service attack (DDoS attack): the incoming traffic originates from many different sources (many IP addresses, on many links, spoofed IP)

Mirai botnet

- Using worms to infect hundreds of thousands of devices
- These infected devices are called bots
- Bots can be instructed to attack networks/servers
- Attack traffic can be 620Gbit/s – 1Tbit/s
- In October 2016, a Mirai botnet attacked Dyn (DNS service) which affected sites such as GitHub, Twitter, Reddit, Netflix, Airbnb

Domain Name System (DNS) is the phonebook of the Internet, translate domain names to IP addresses. Using TCP/UDP port 53.

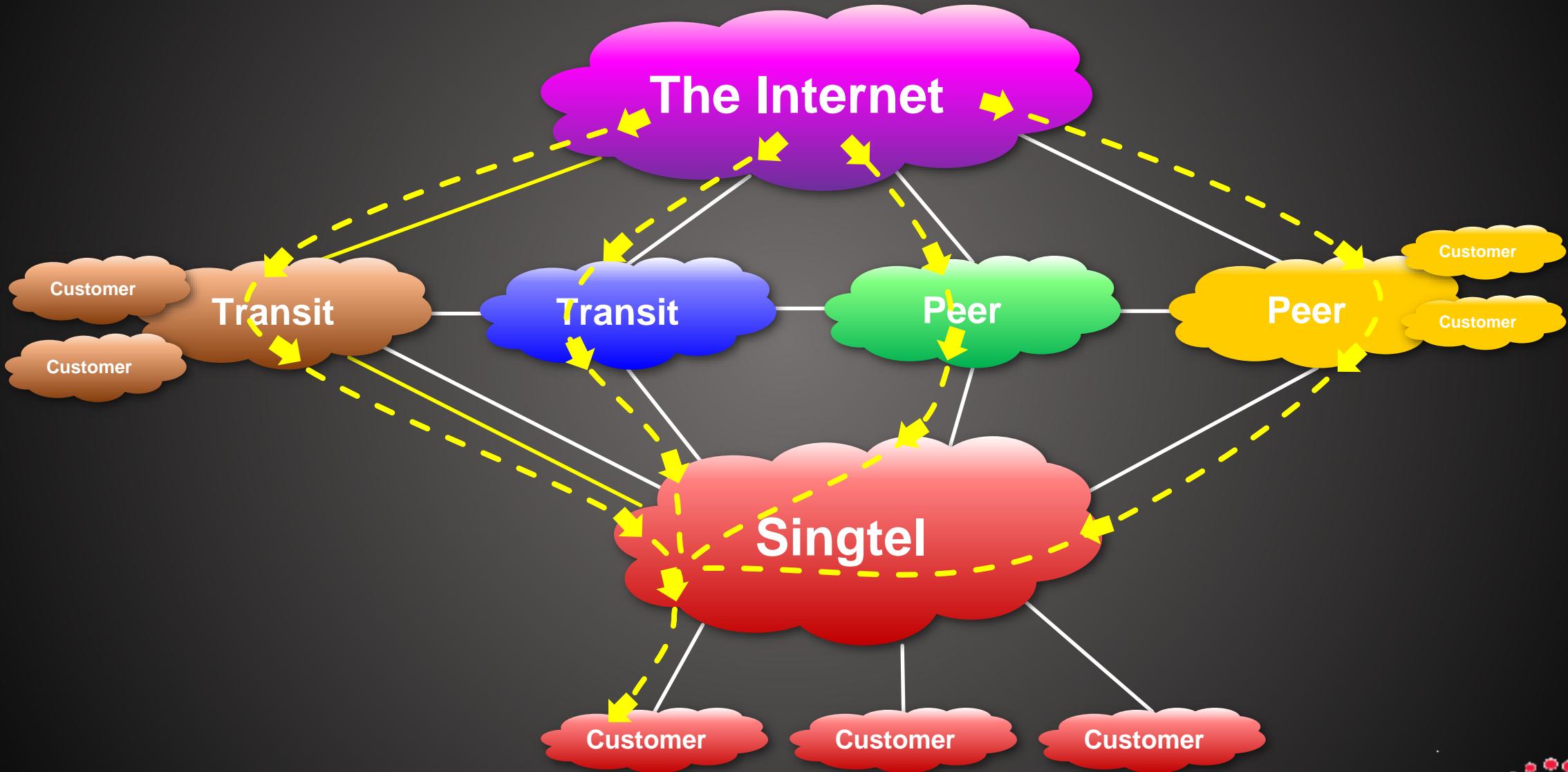
Attack to DNS system

- AWS (Amazon Web Services) hit by DDoS attack in Oct 2019
- DNS systems are being jammed by a flood of requests
- DDoS mitigation inadvertently drop some legit domain-name queries
- Intermittent errors with name resolution of some AWS DNS names

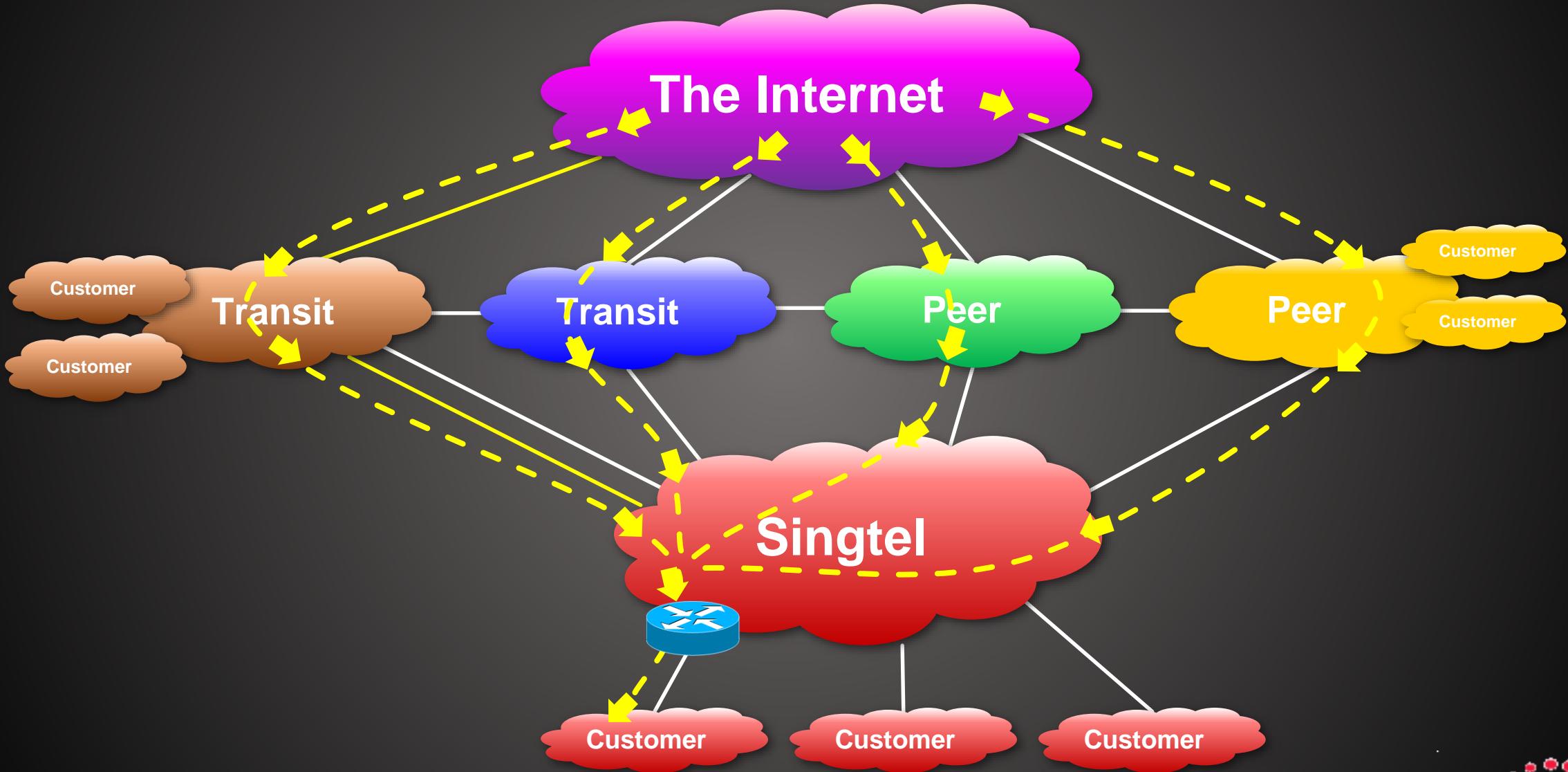
Mitigate DDoS attack

- ❖ ACL (Access List)
 - Manual configuration
 - Drop all traffic to destination IP
- ❖ RTBH (Remotely-Triggered Black Hole)
 - Using BGP protocol – supports automation
 - Drop all traffic on all border routers to destination IP
- ❖ BGP Flowspec (RFC 5575)
 - Using BGP protocol – supports automation
 - Drop/rate-limit: source/destination IP, TCP/UDP ports
- ❖ Scrubbing Center
 - A centralized data cleansing station where traffic is analysed and malicious traffic (vulnerabilities and exploits) is removed
 - Using BGP protocol – supports automation
 - On premise/POP or in the Cloud

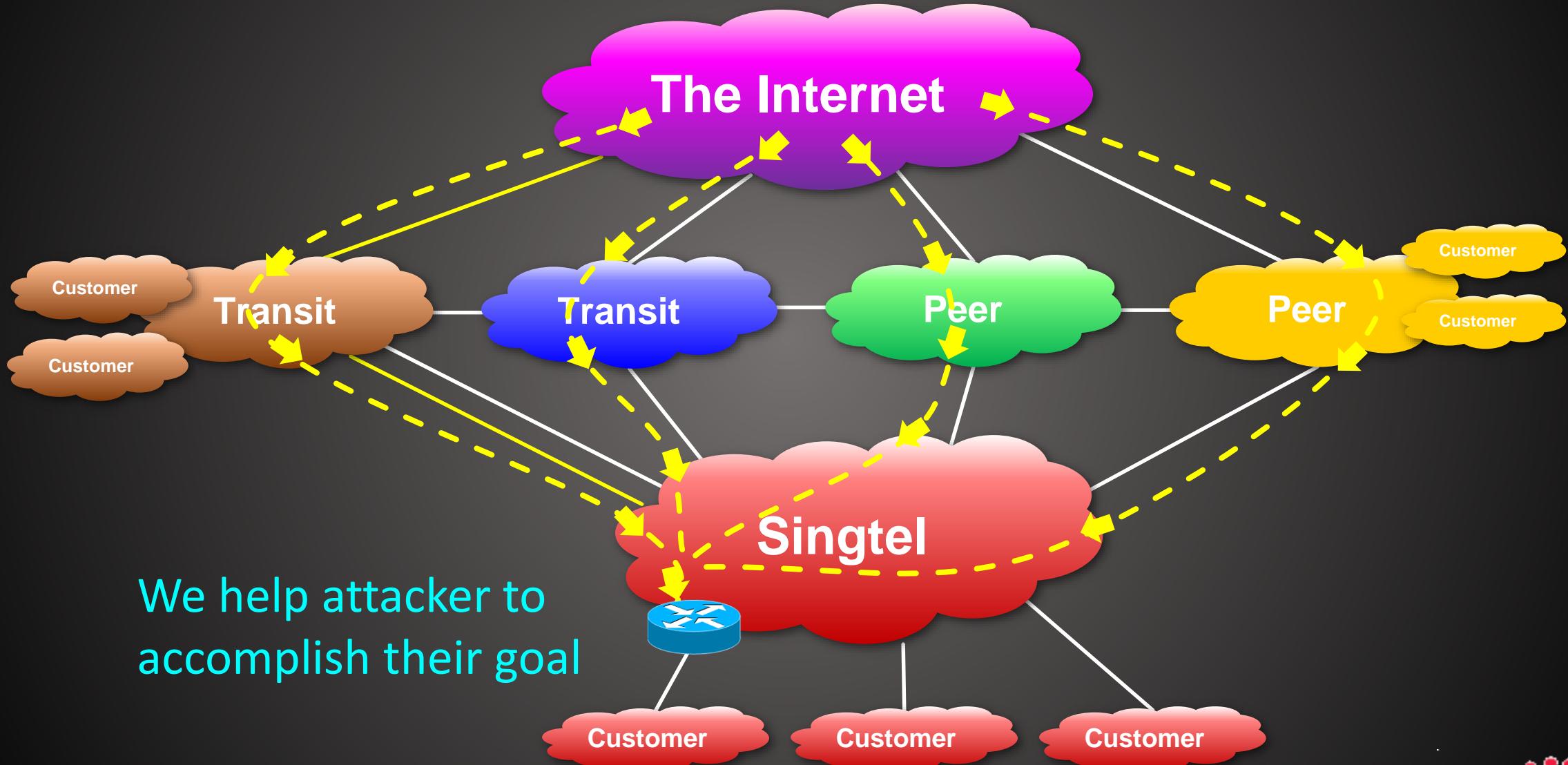
DDOS Attack



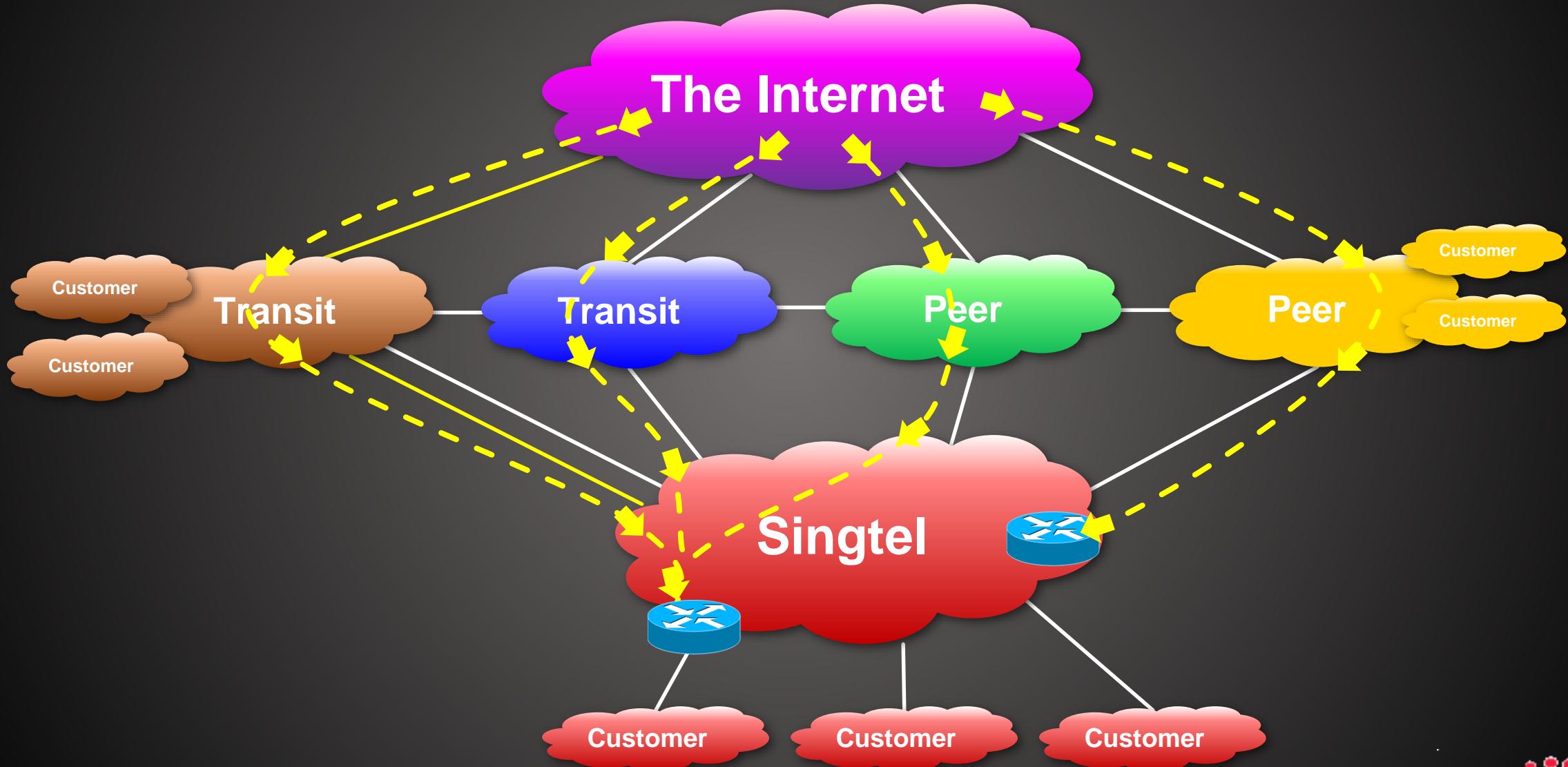
DDOS Attack



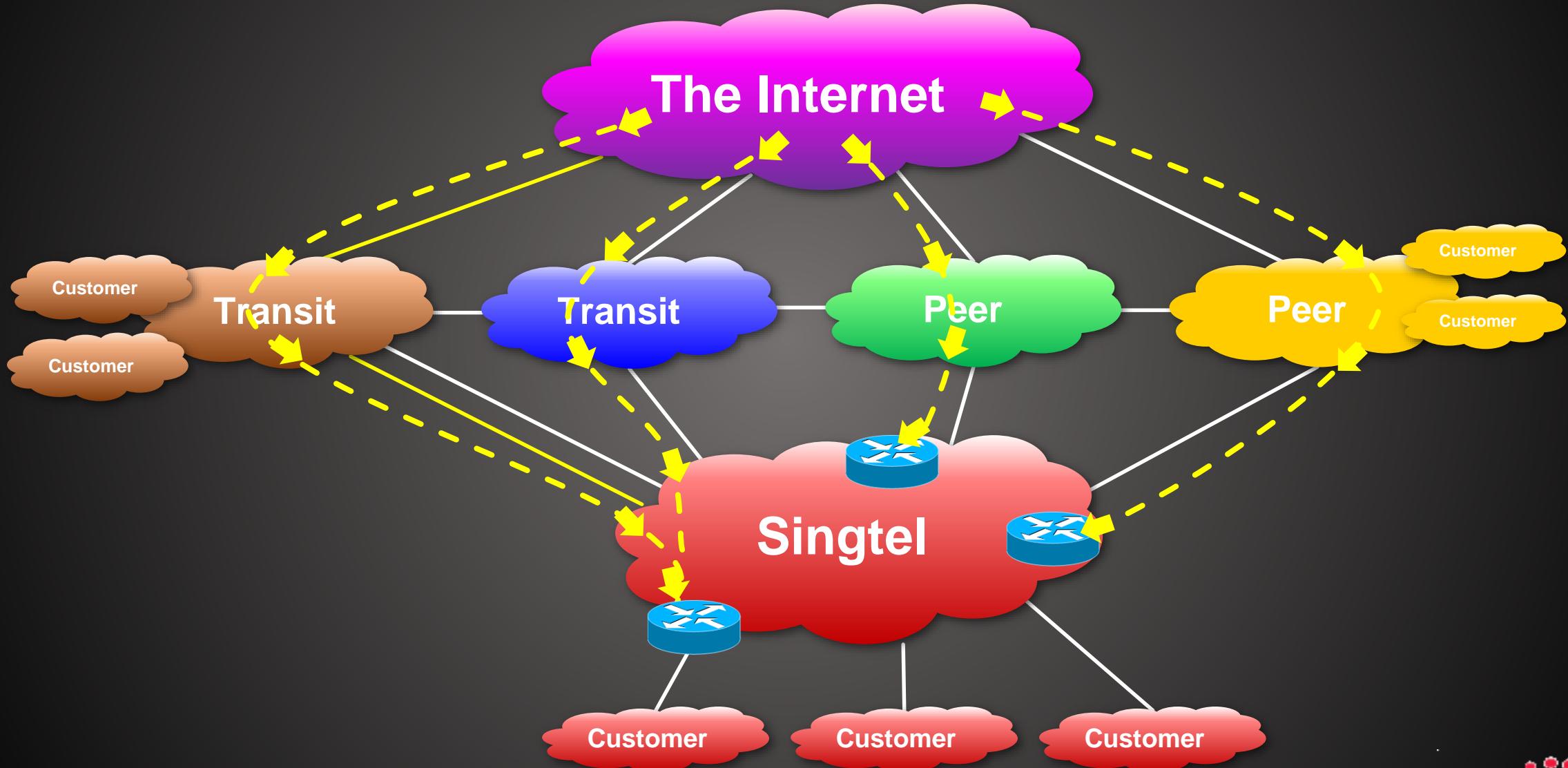
ACL (Access List)



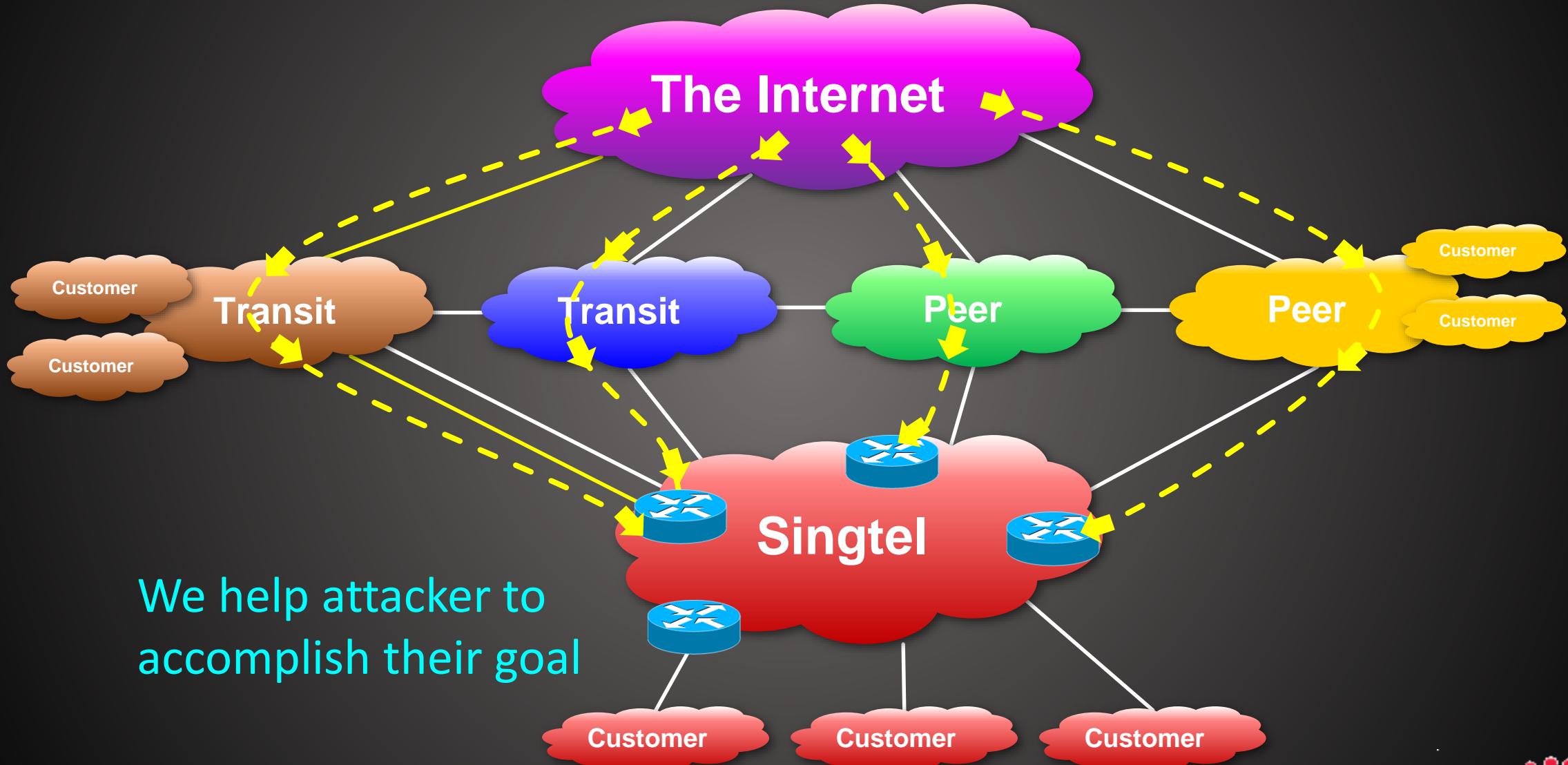
ACL (Access List)



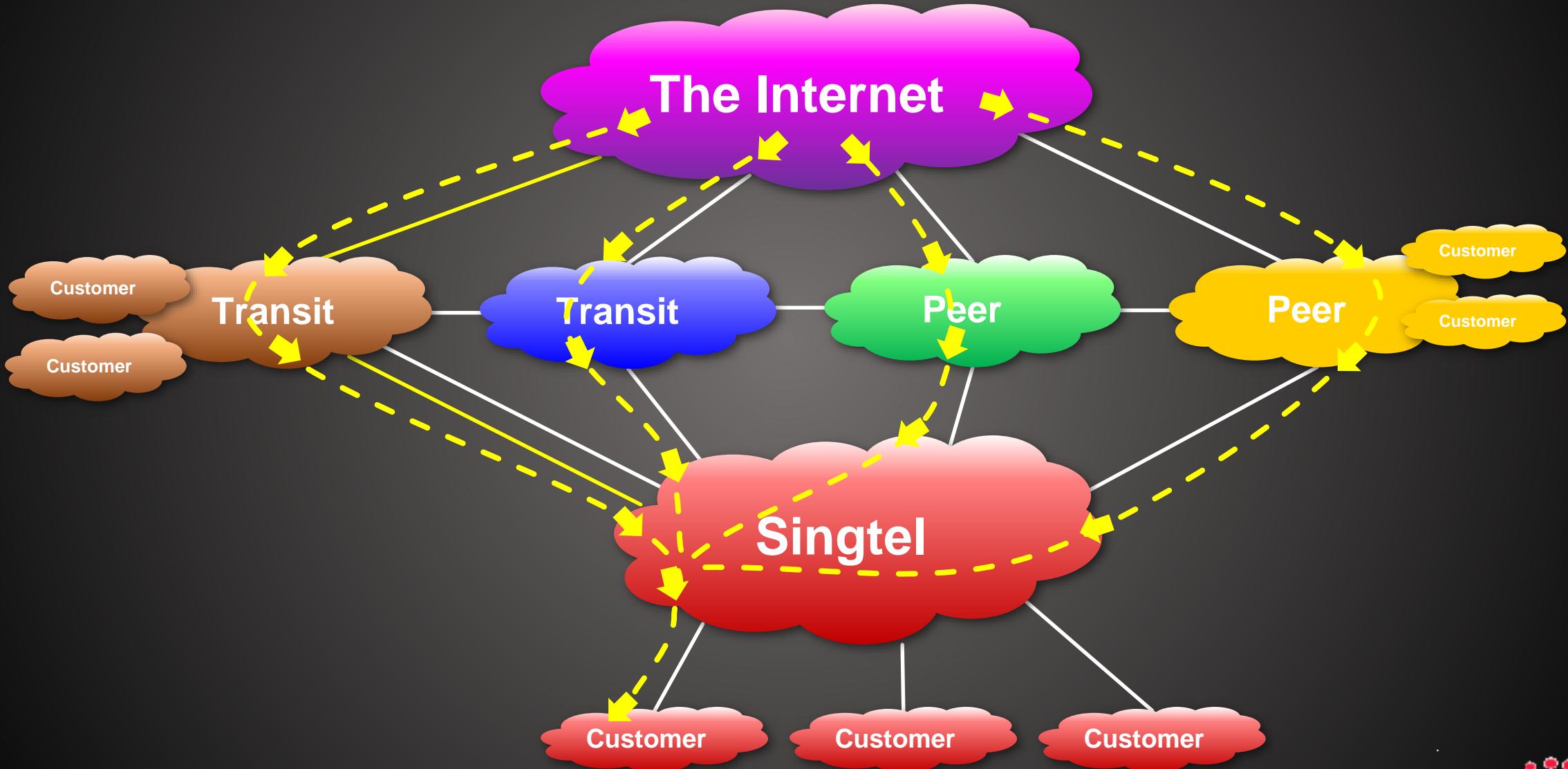
ACL (Access List)



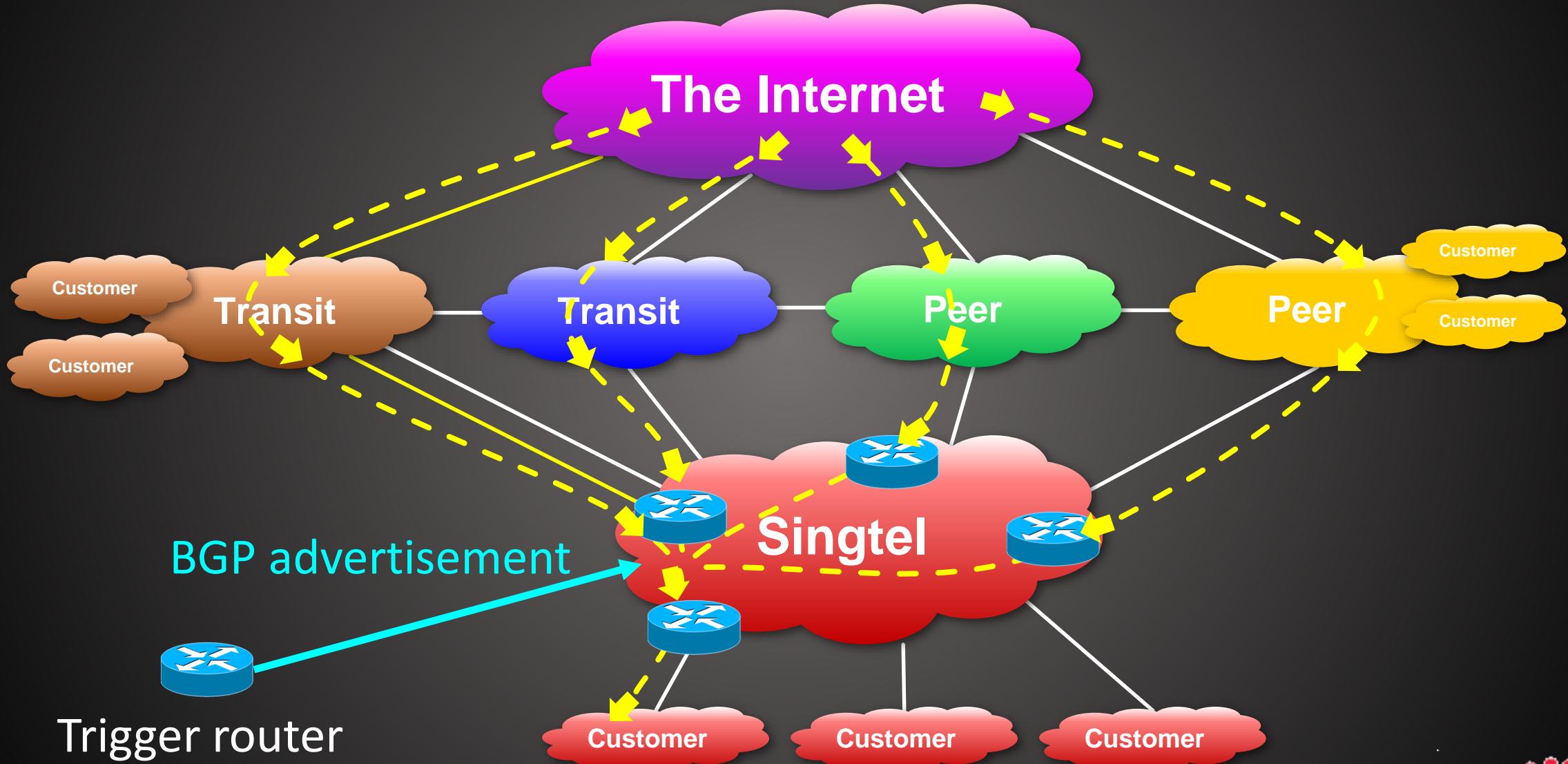
ACL (Access List)



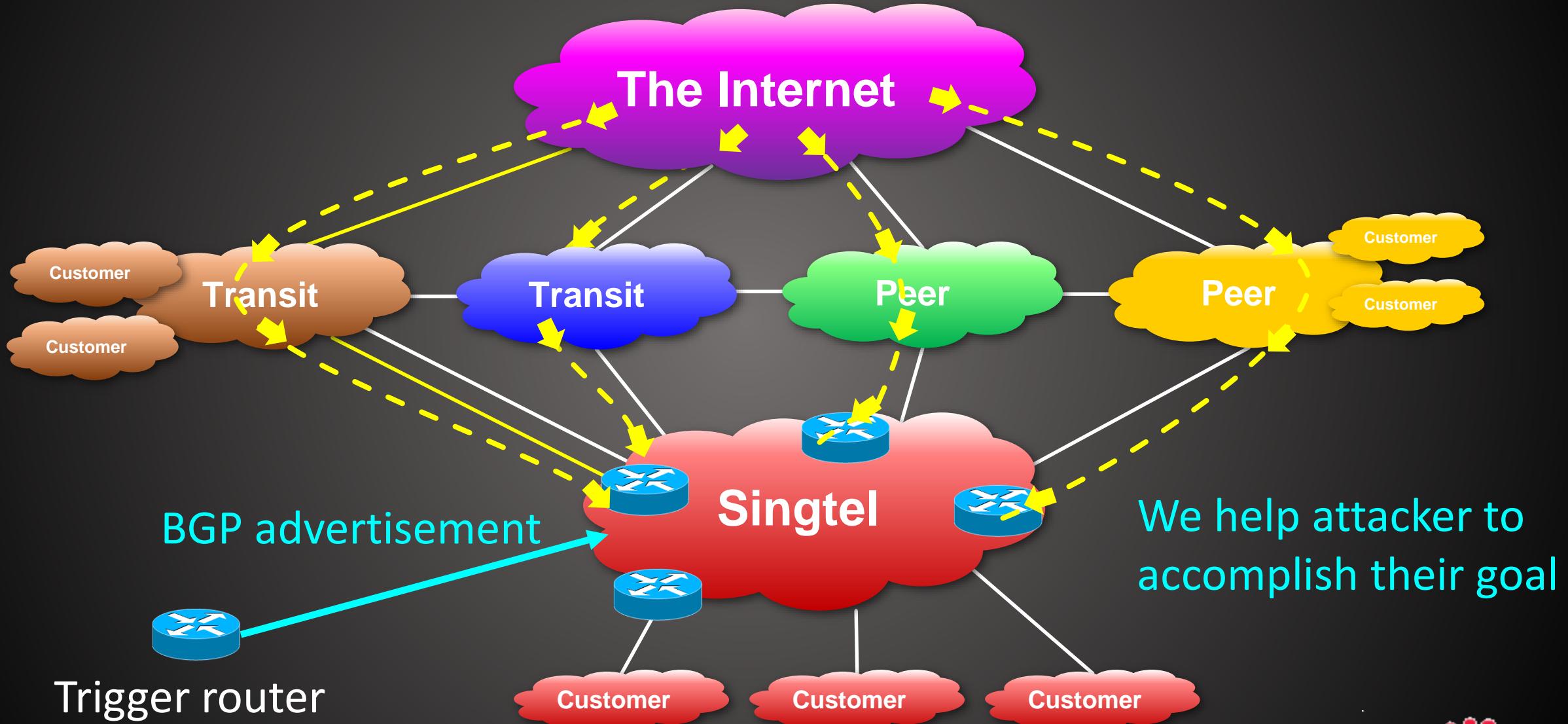
DDOS Attack



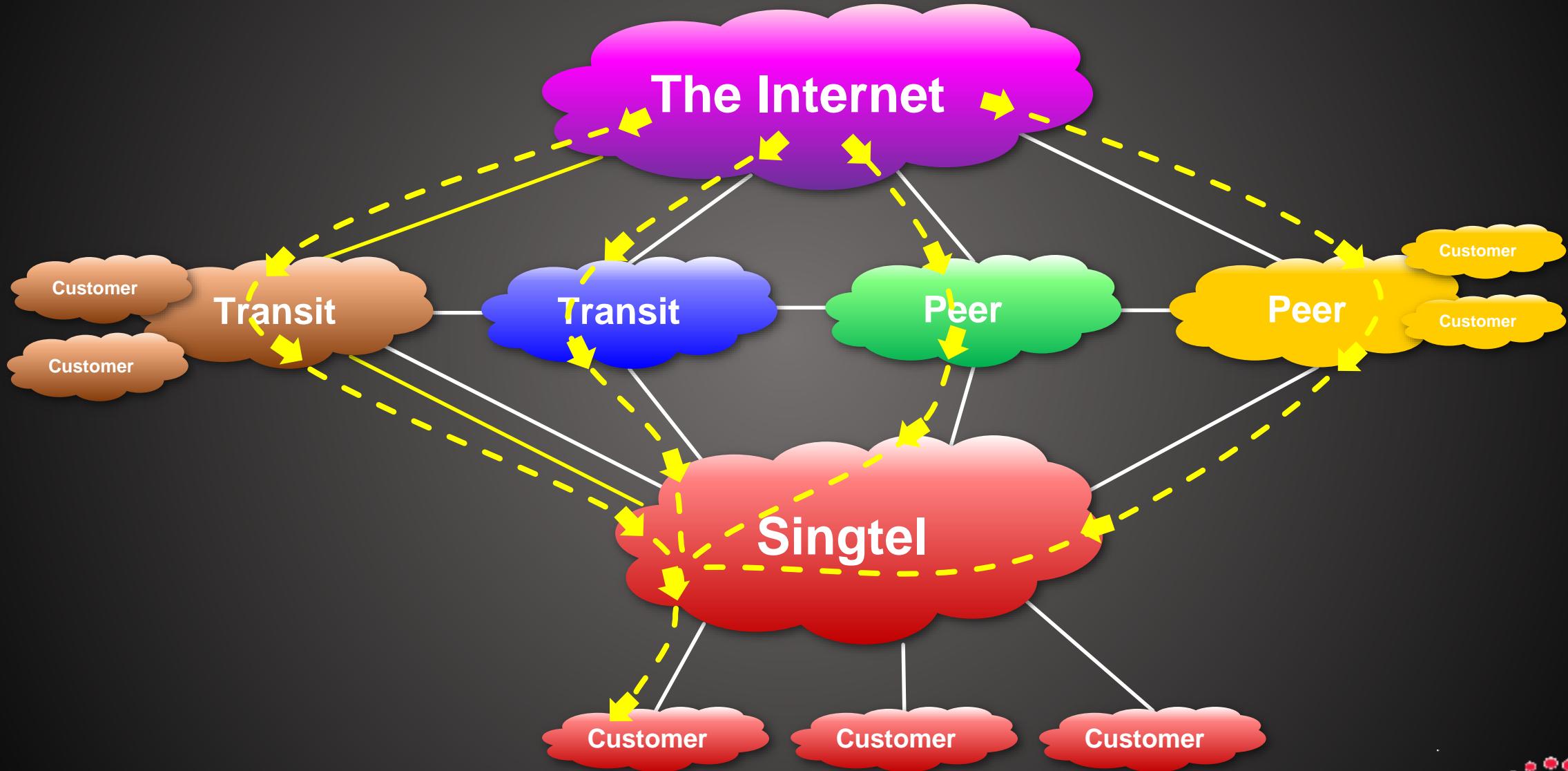
RTBH (Remotely-Triggered Black Hole)



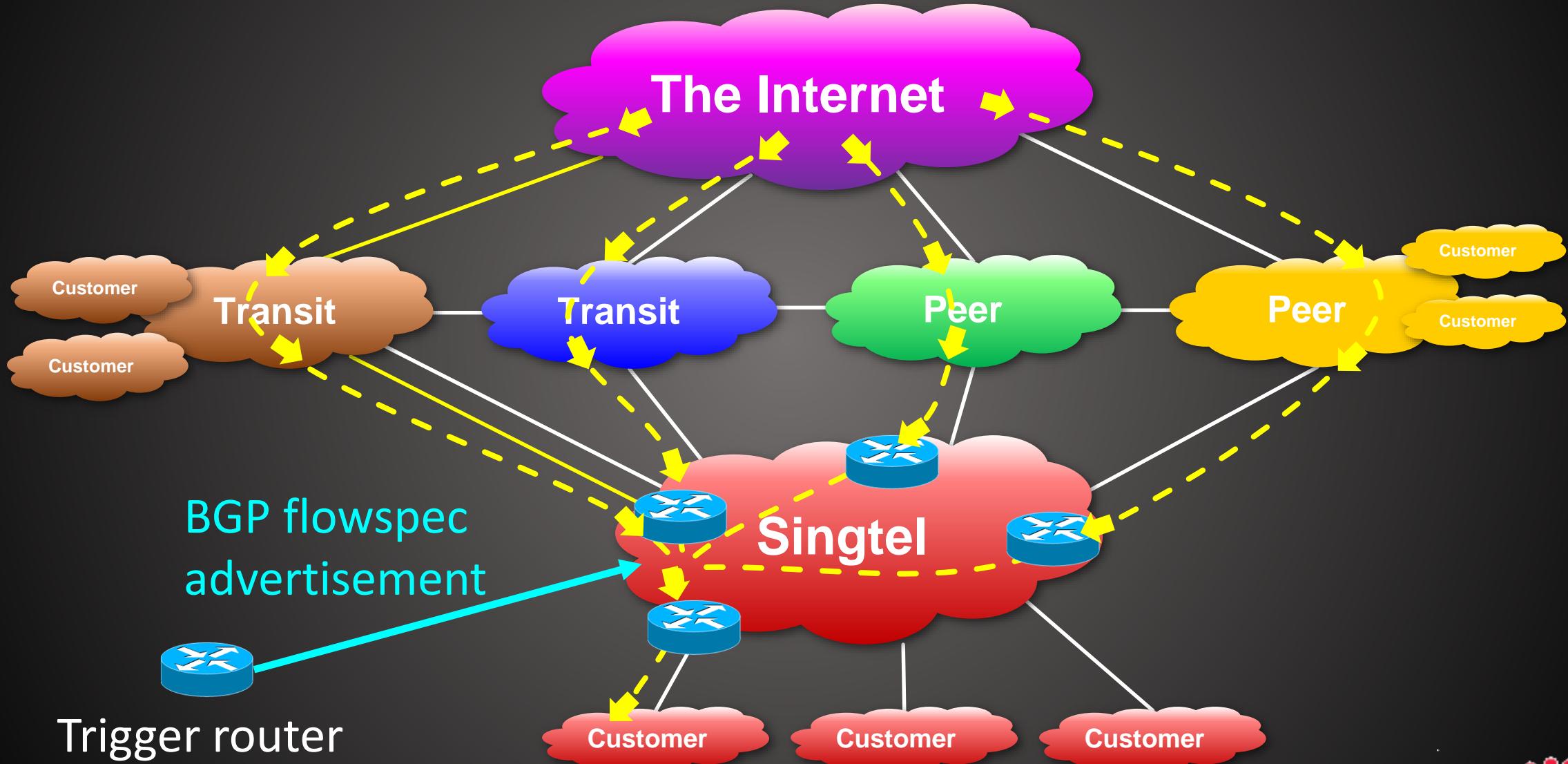
RTBH (Remotely-Triggered Black Hole)



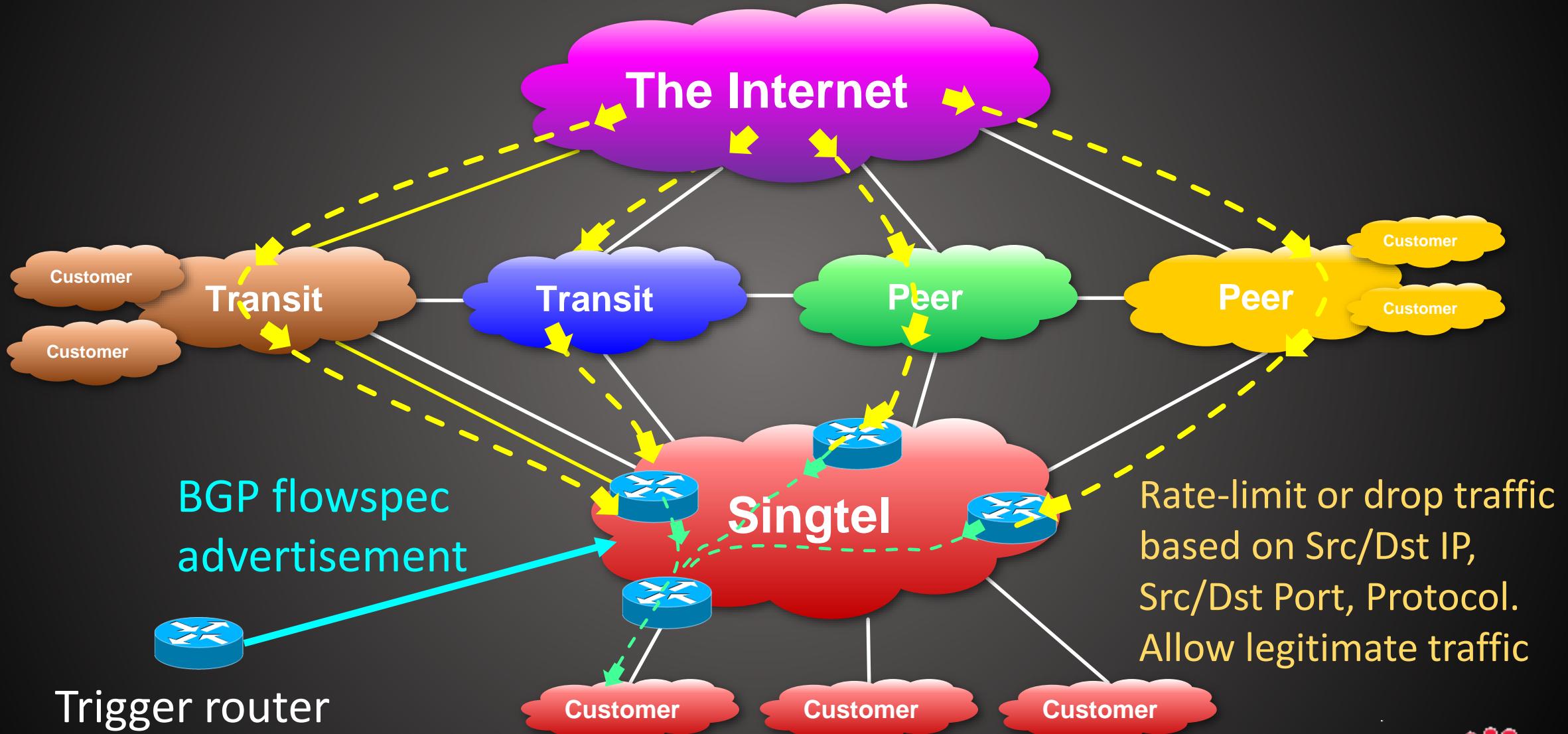
DDOS Attack



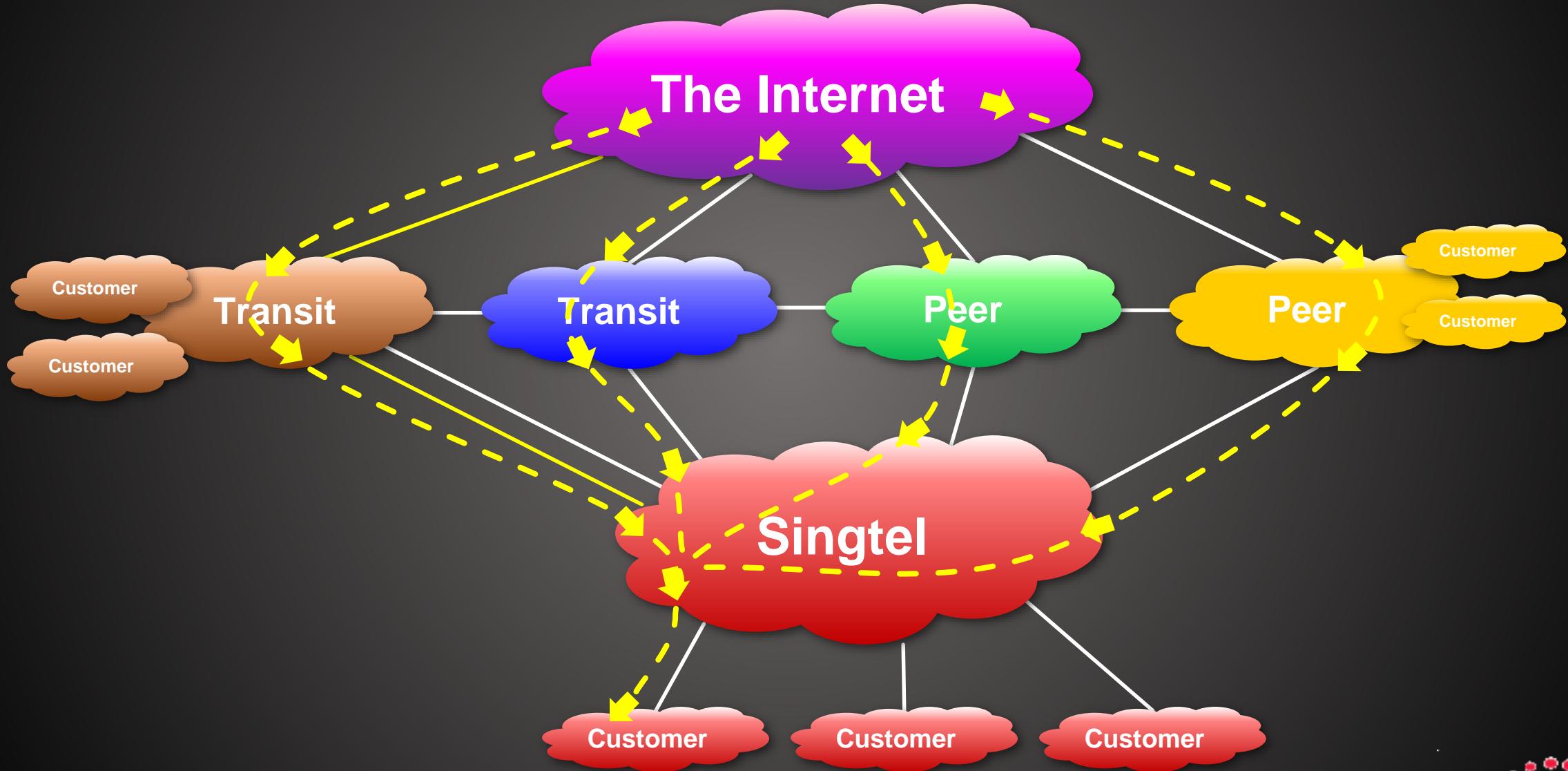
BGP Flowspec



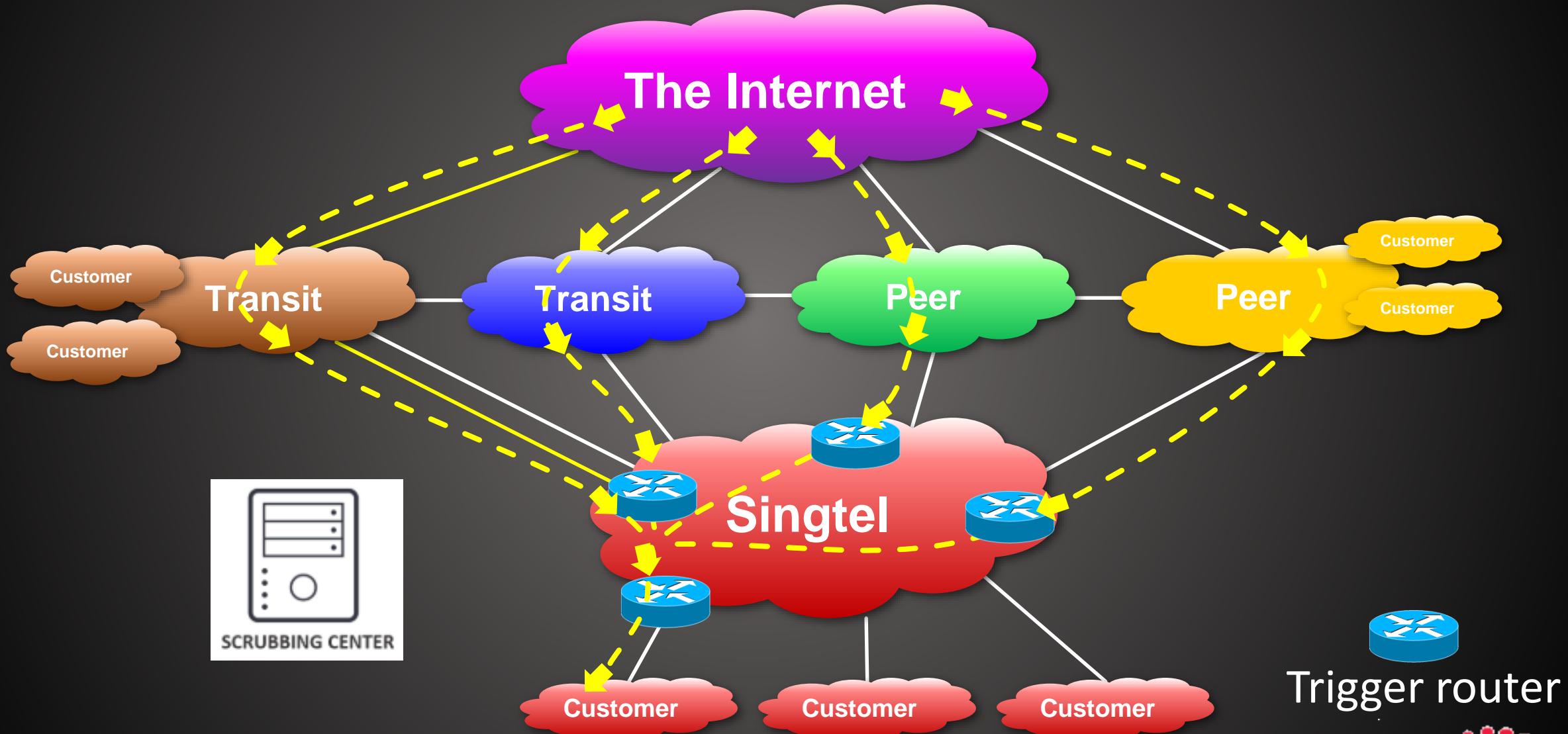
BGP Flowspec



DDOS Attack

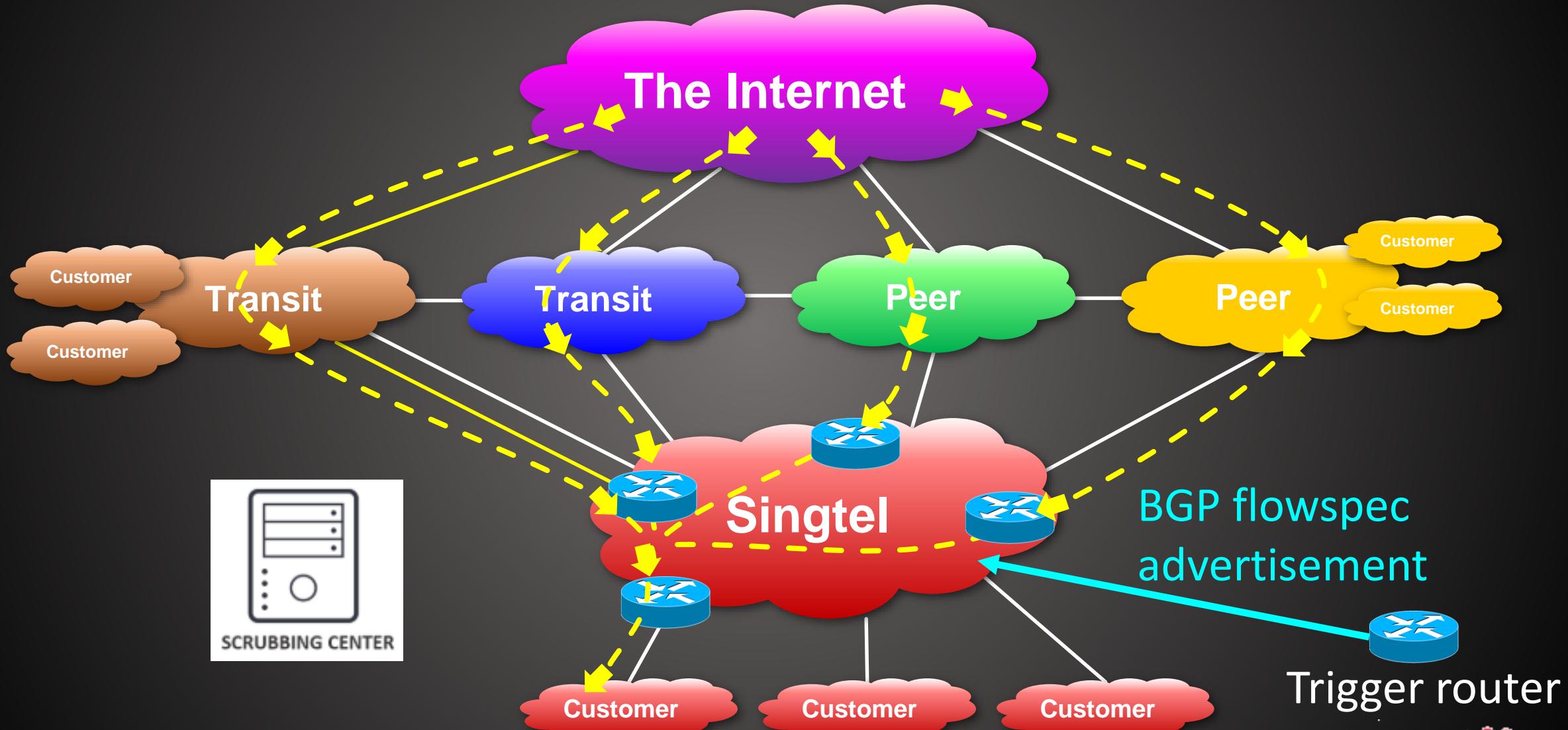


Scrubbing Center

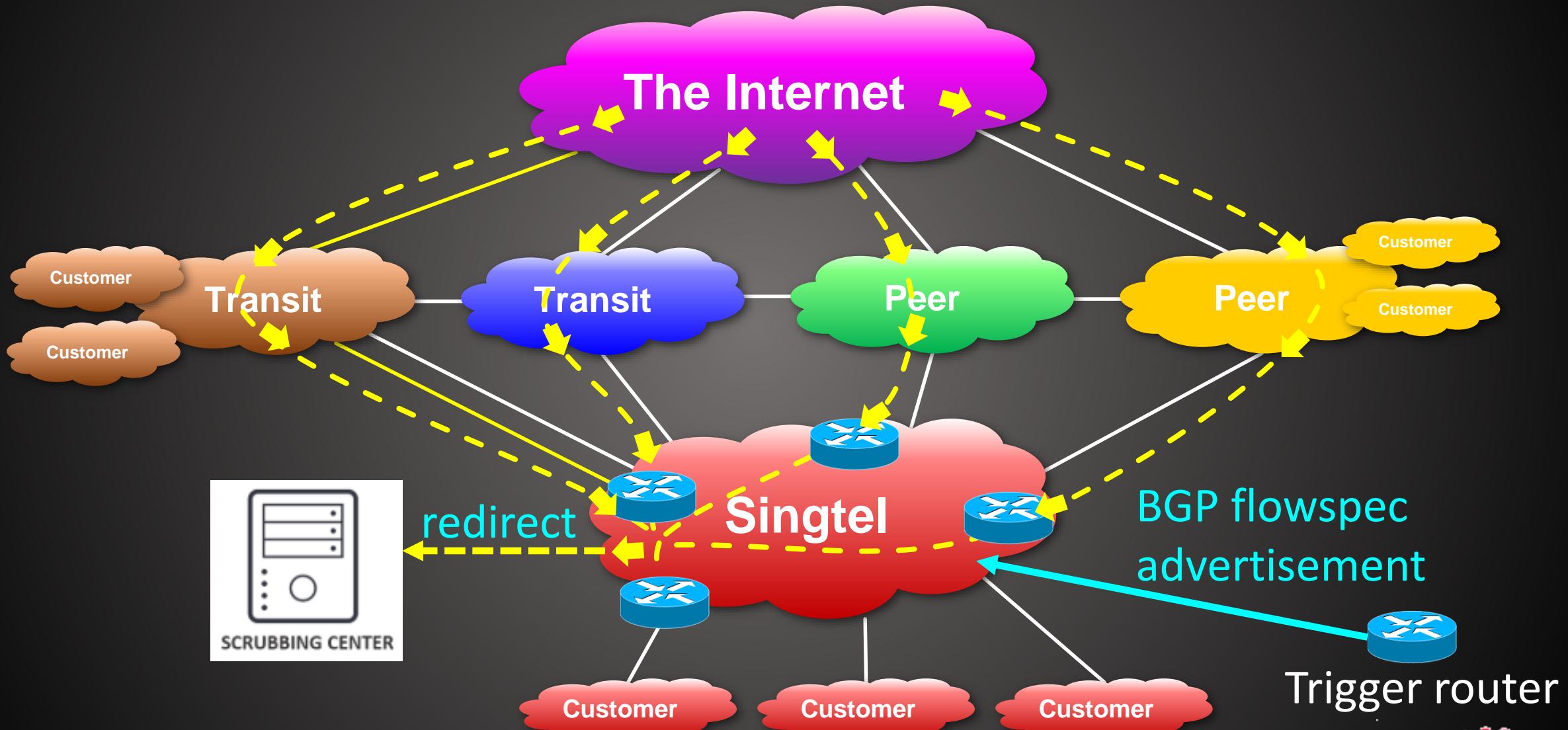


Trigger router

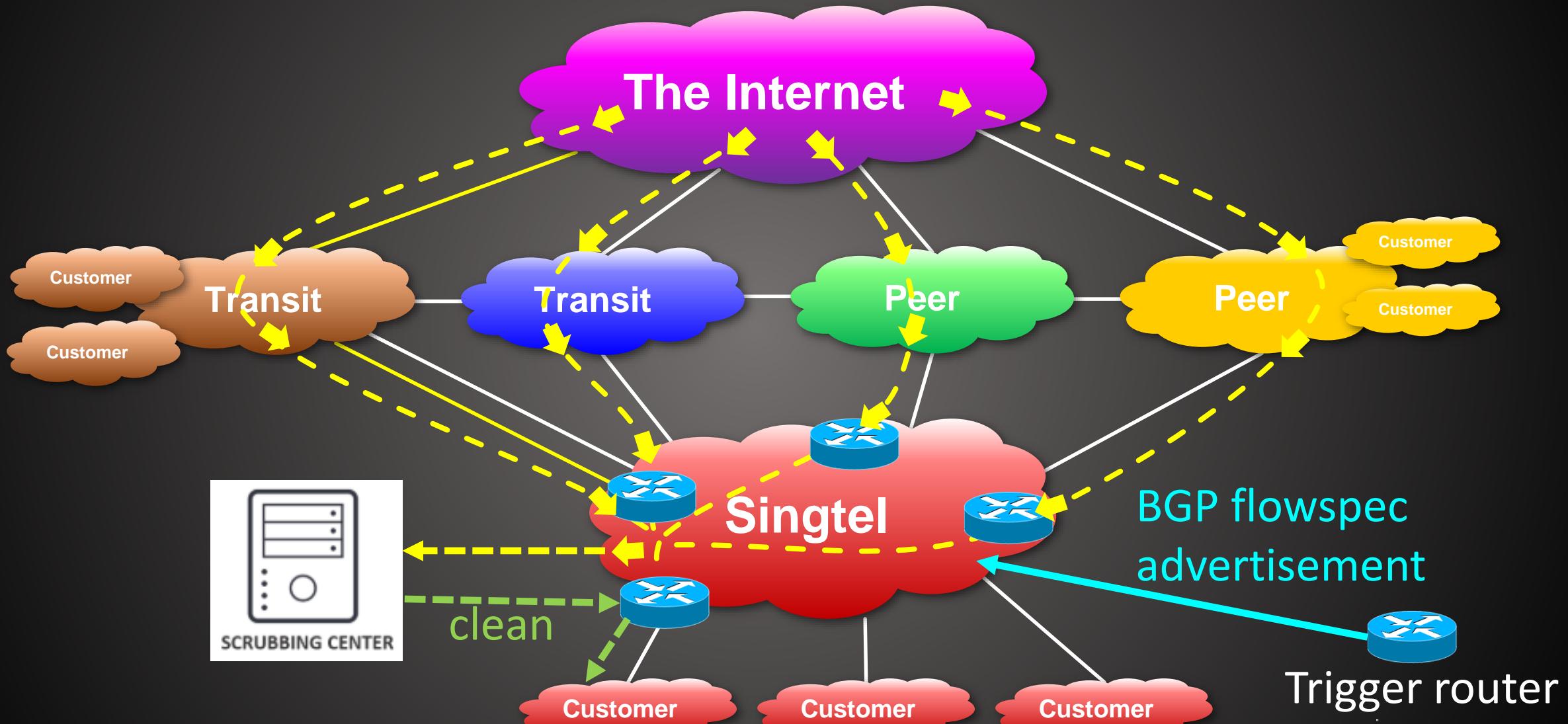
Scrubbing Center



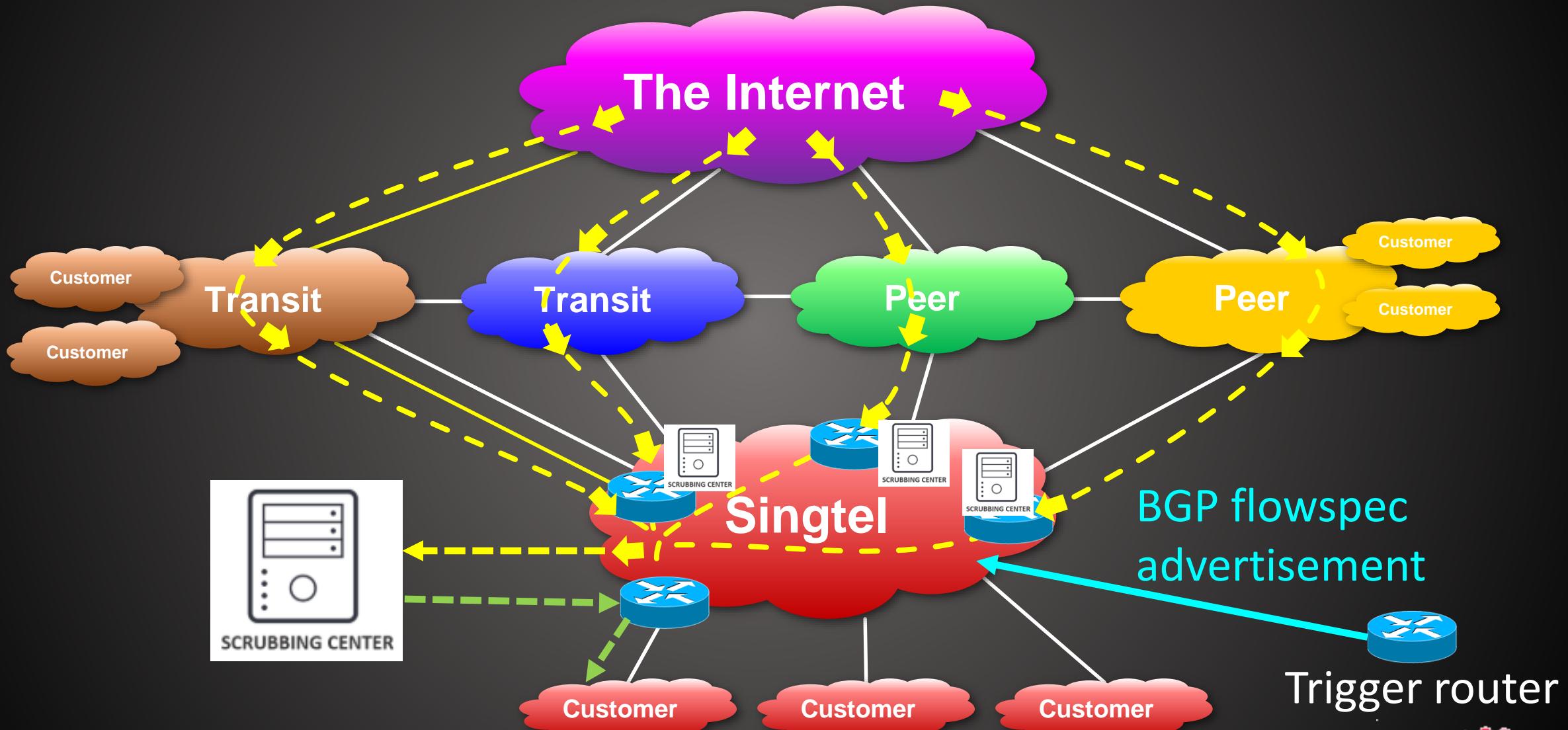
Scrubbing Center



Scrubbing Center



Scrubbing Center



A Brief History of SDN & NFV

2000-2005

2005-2010

2011

2012

2013

2014

2015



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A Brief History of SDN & NFV

2000-2005

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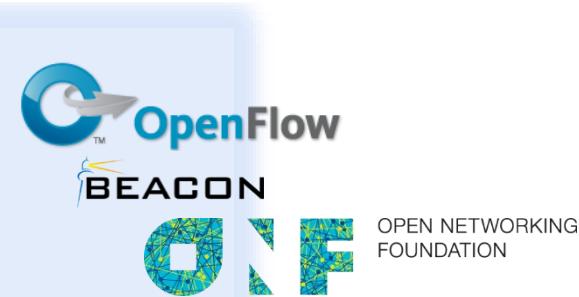
2011

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A Brief History of SDN & NFV

2000-2005

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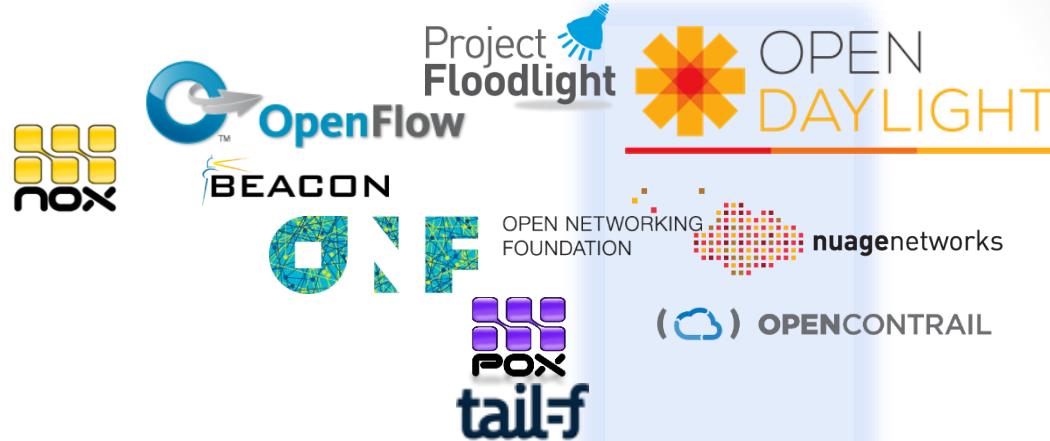
2014

2015



A Brief History of SDN & NFV

2000-2005	2005-2010	2011	2012	2013	2014	2015
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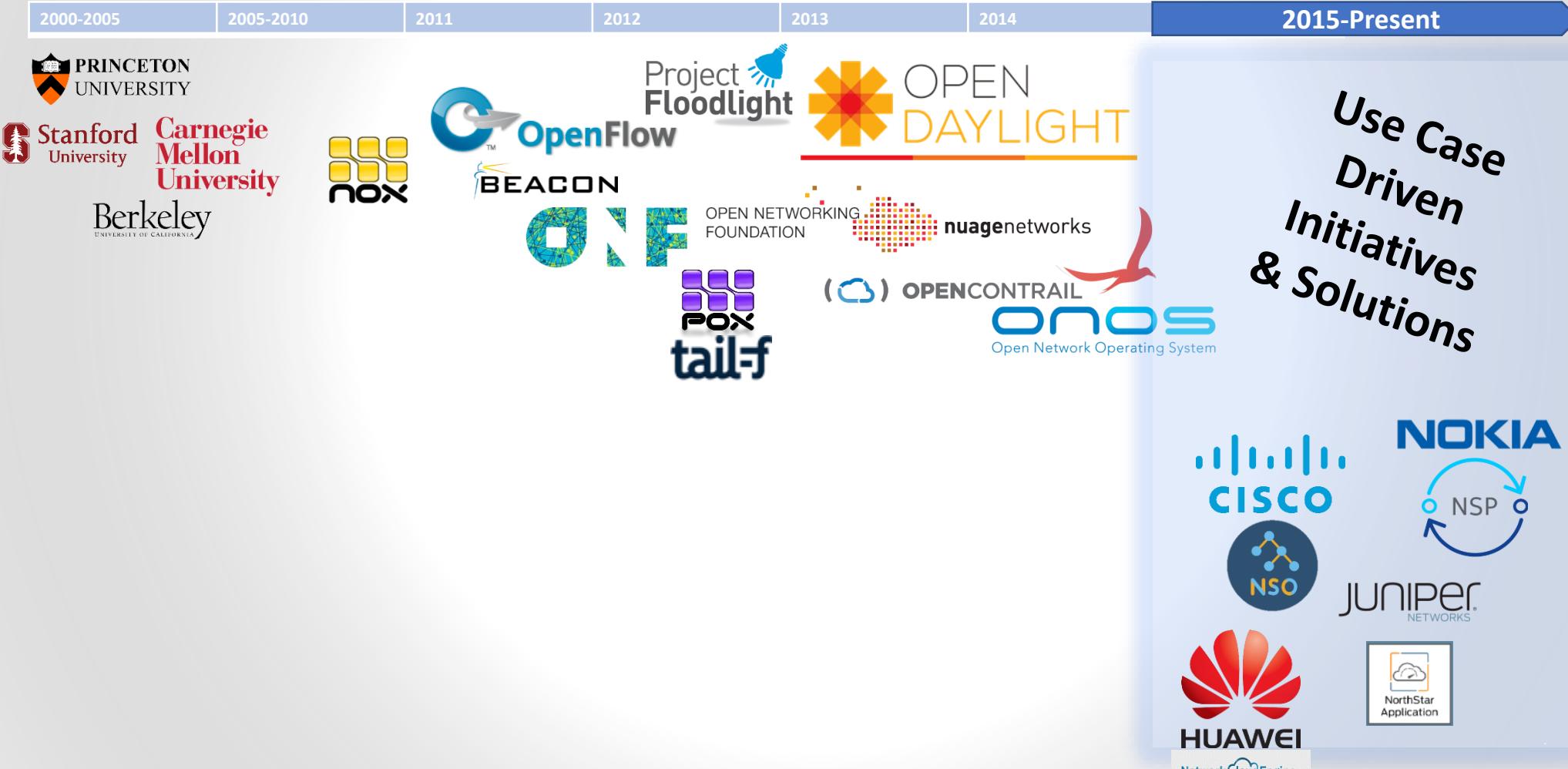


A Brief History of SDN & NFV

2000-2005	2005-2010	2011	2012	2013	2014	2015
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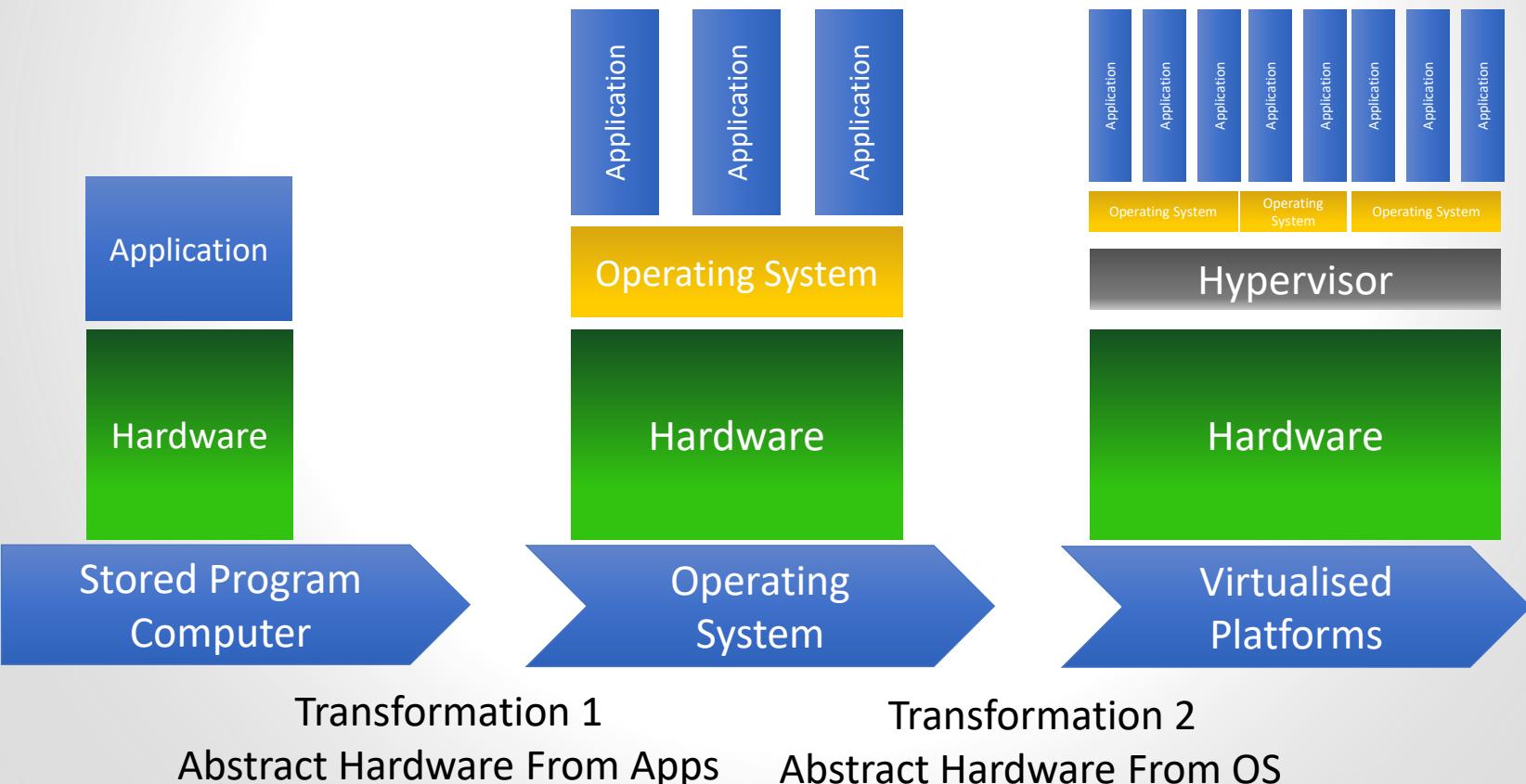
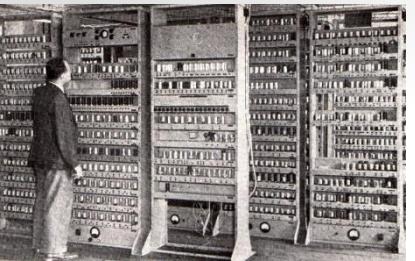


A Brief History of SDN & NFV

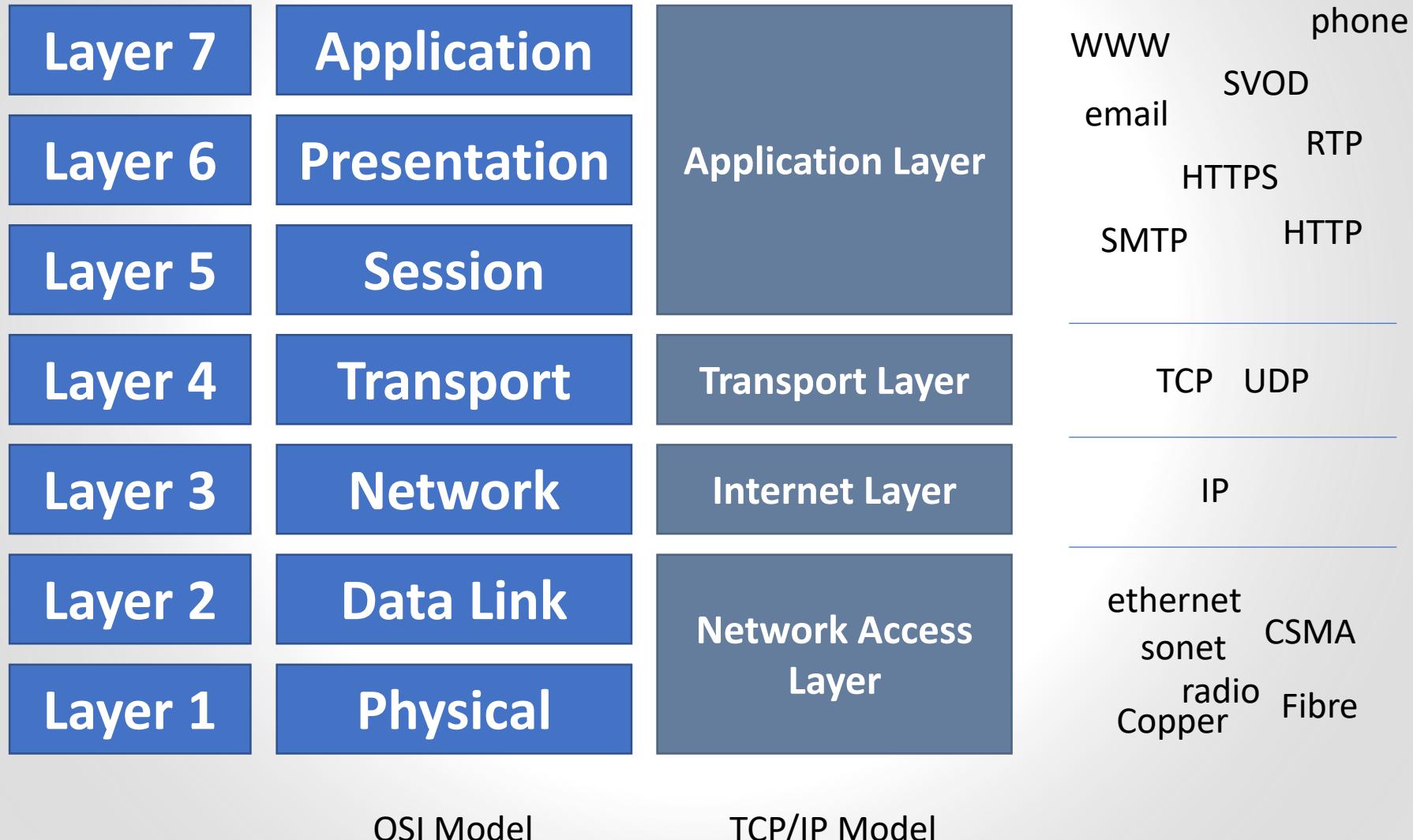


What Is SDN

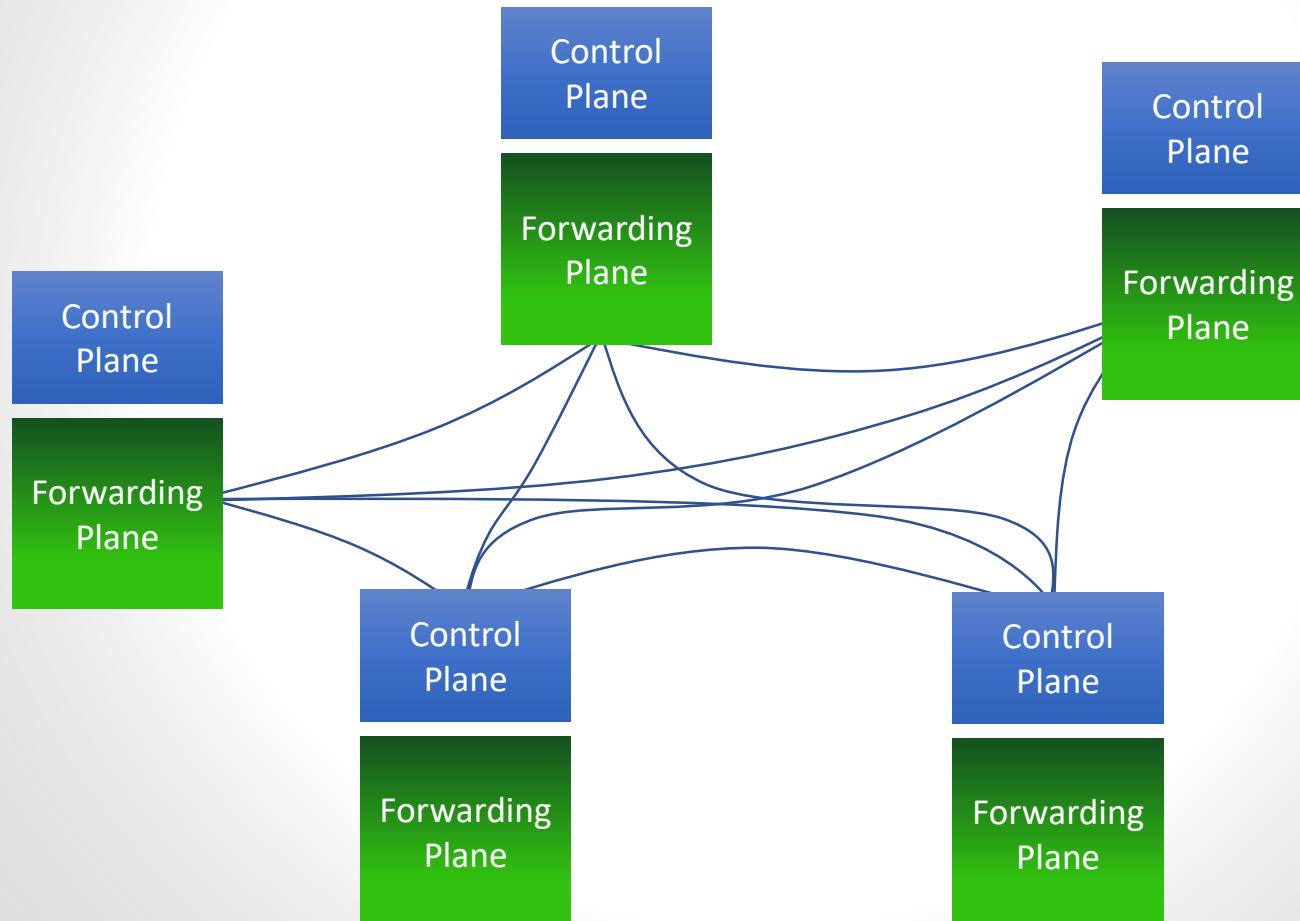
Key Concept: Abstraction



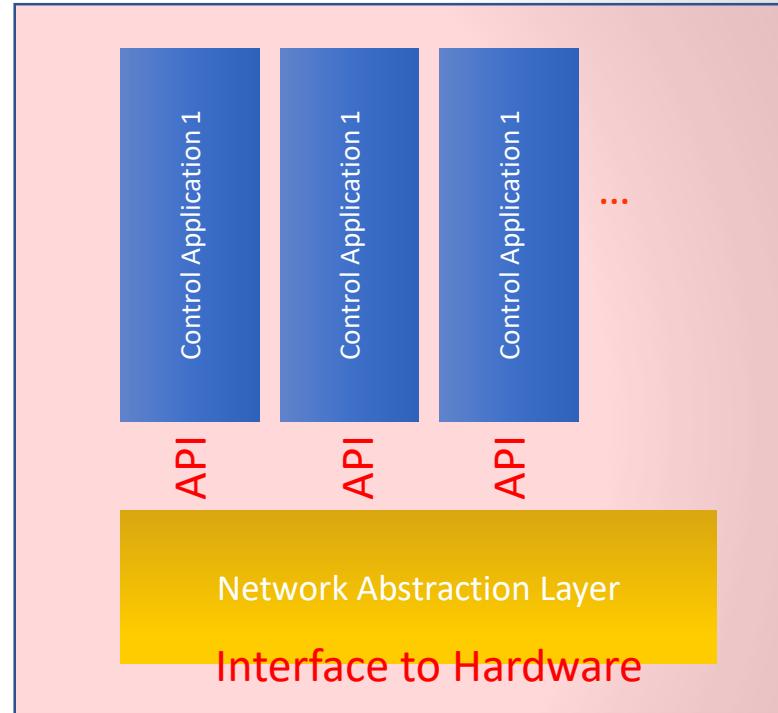
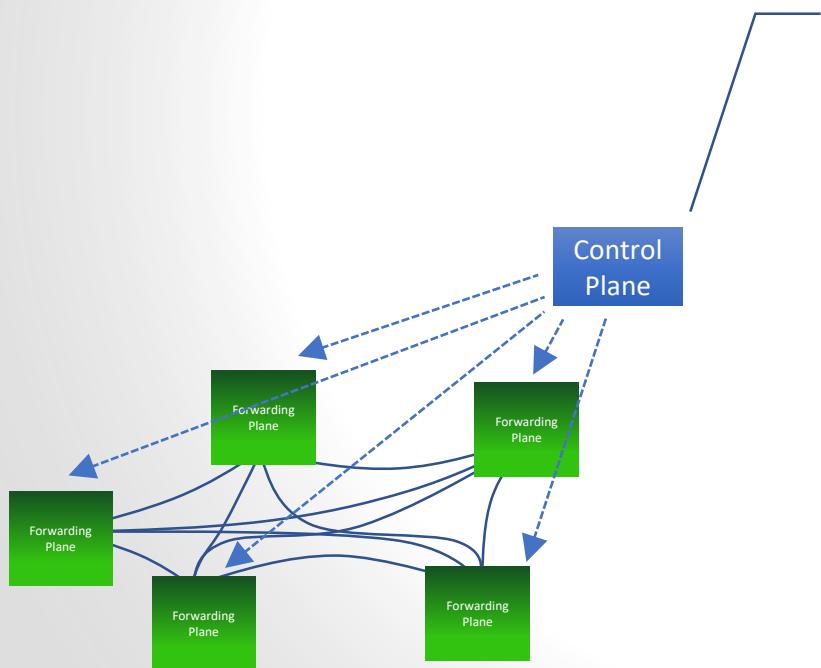
But Networks Already Have Abstractions



Abstraction in the network



SDN – Separate Control from Forwarding Planes



Benefits of Abstracting the Network

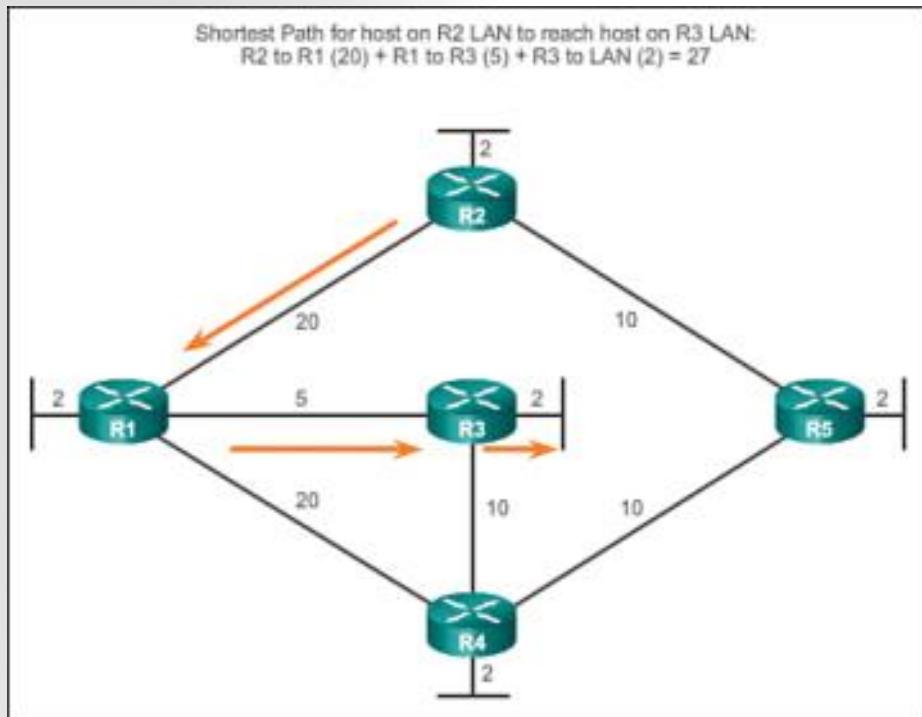
PROGRAMABILITY - AGILITY – REUSABILITY – FLEXIBILITY

- This creates new possibilities not previously available
- Creates a programmable platform from the network
- Write once and reuse on different hardware
- Enables
 - Agile services
 - Can give customer control of product
 - Faster time to market
 - Network management (Traffic Engineering)

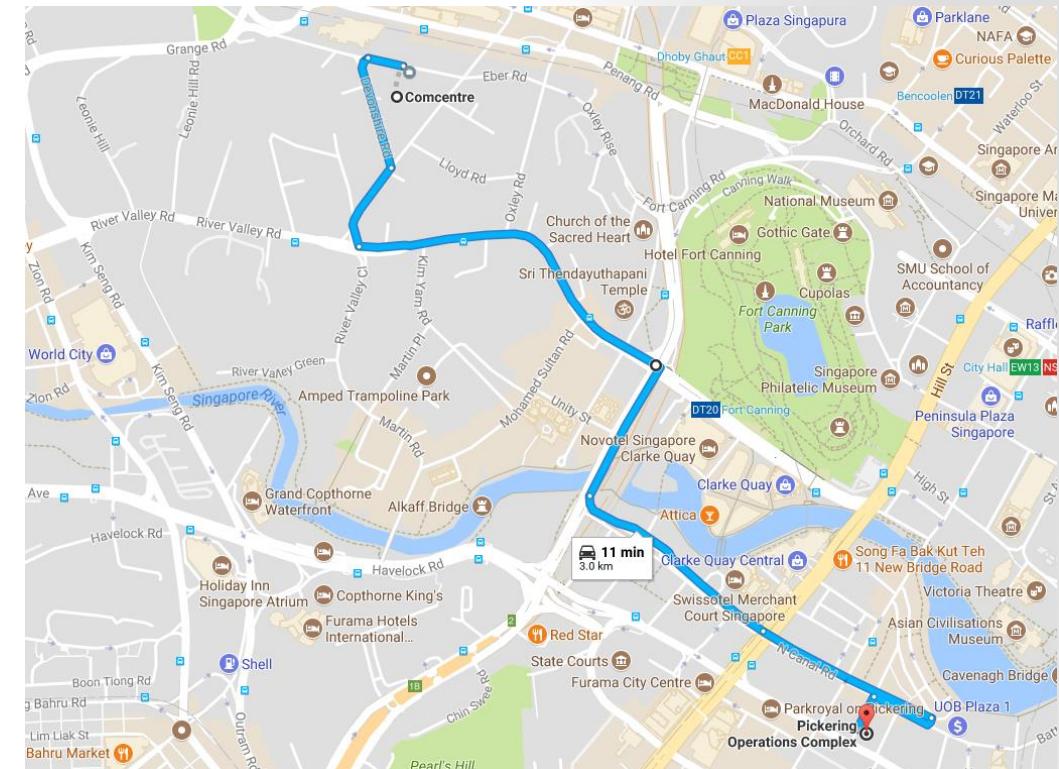
Abstraction: So What?

Fundamentally, Networking is about transporting packets from one point to another.

Traditional networks rely on a fixed path from source to destination. Routing algorithm computes the Shortest Path to reach the destination.



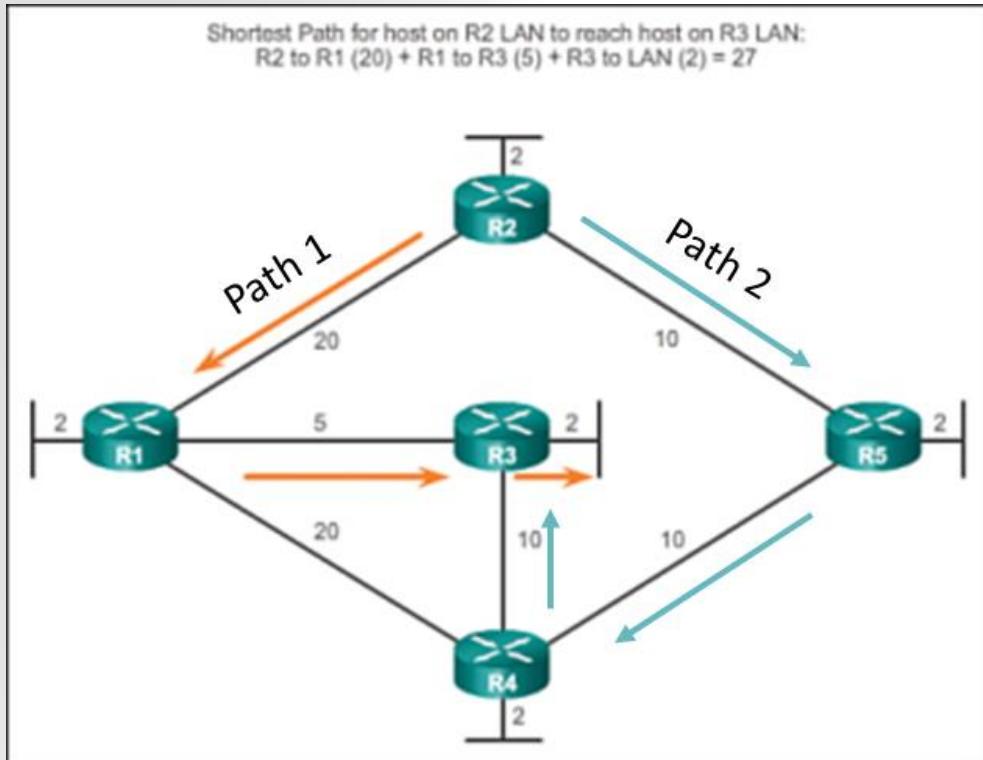
This is analogous to vehicle transport network with one path (shortest path) from A to B.



Abstraction: So What?

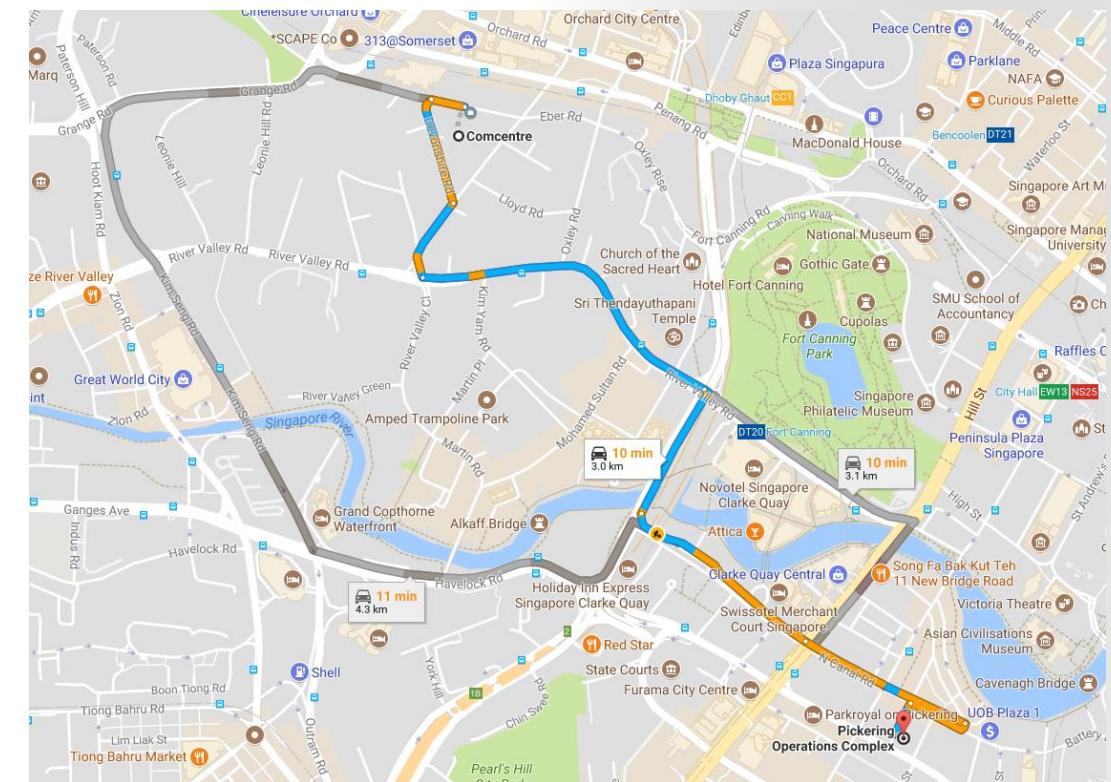
Traffic Engineering manually steers traffic to alternate pre-defined routes.

With Traffic Engineering, alternate paths can be set up for certain defined traffic. This process is manual.



Traffic Engineering sets up alternate paths

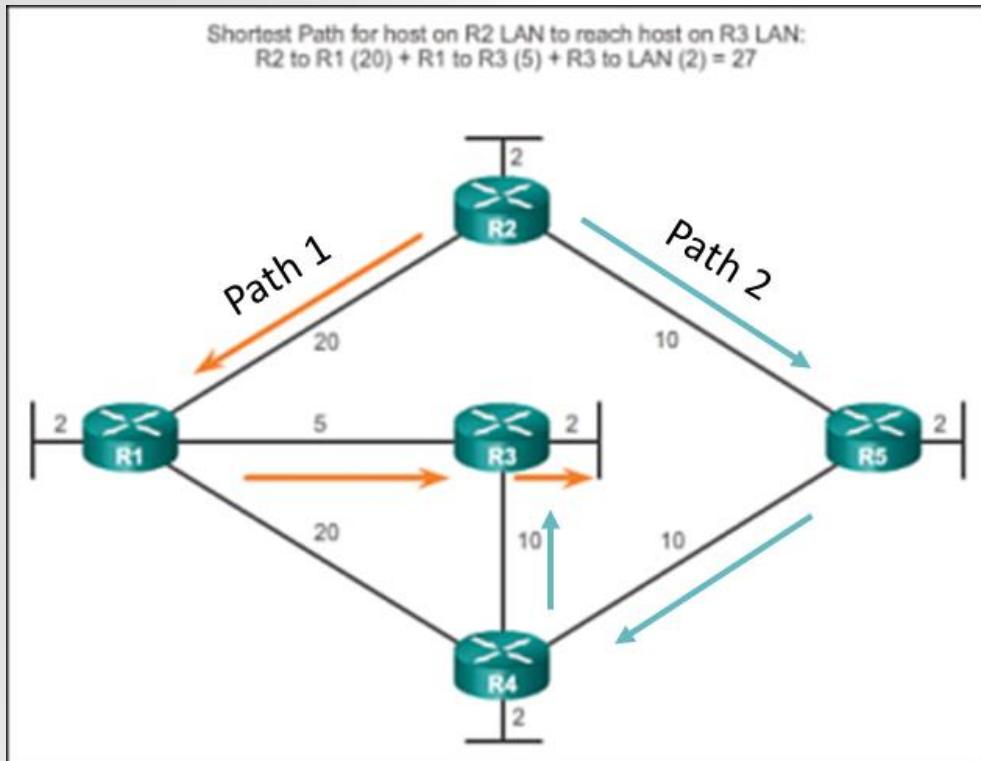
This is analogous to having 2 roads from A to B, but only cars with odd-numbered plates can go on Route A while even-numbered plates go on Route B.



Abstraction: So What?

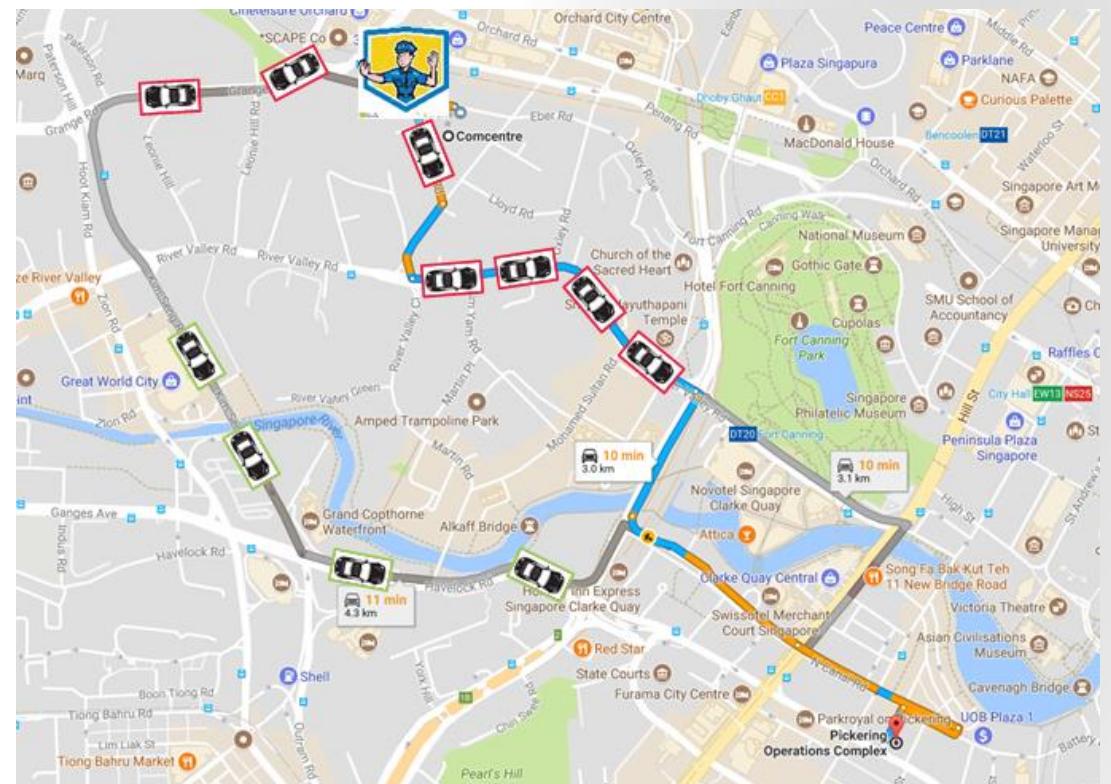
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Abstraction: So What?



What we want is a network which dynamically routes traffic depending on information, such as traffic jams, roadworks etc.

To do this we need some centralized control which has knowledge of the entire network state

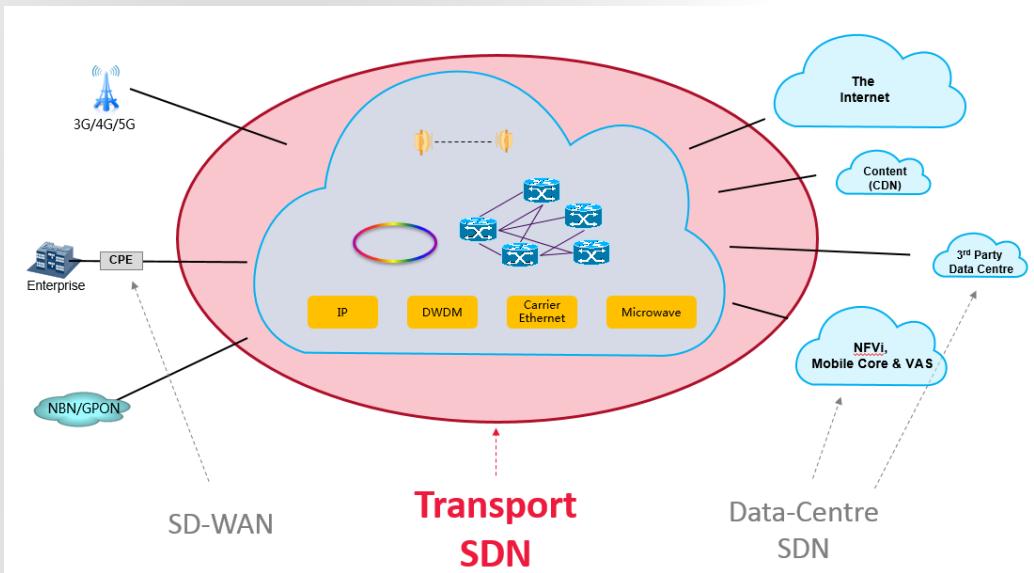
The Goal Of SDN



- Centralised controller;
- Real-time Traffic visibility;
- Algorithm-based Traffic optimization and control;
- API-based provisioning.
(Network Slicing requirement)

Singtel – Software Defined Transport Network

Scope & Uses of Transport SDN (T-SDN)

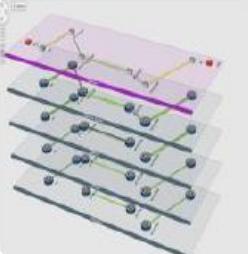
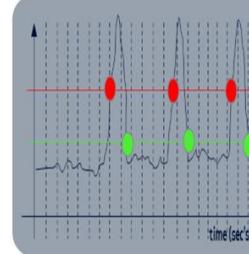
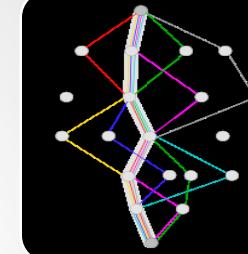
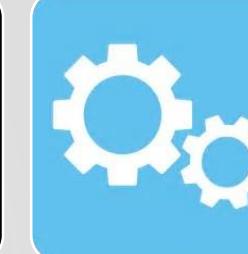


Key Drivers

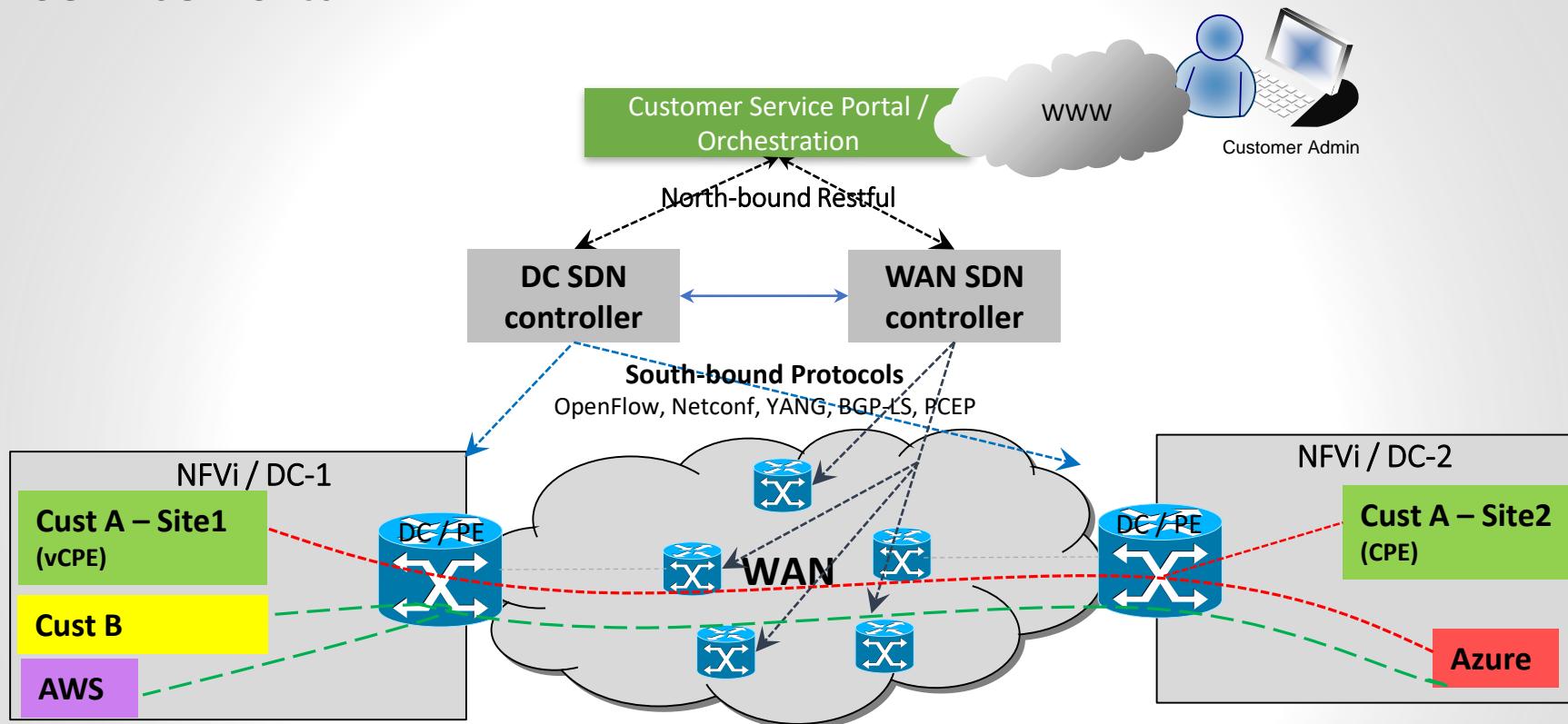
API-enabled Centralised Control across different transport networks allow :-

1. Fast turnaround for creating & provisioning new services;
2. Central optimized traffic engineering (allowing traffic steering and network optimization);
3. Network Slicing for 5G;
4. Automation.

SDN Capabilities & Uses

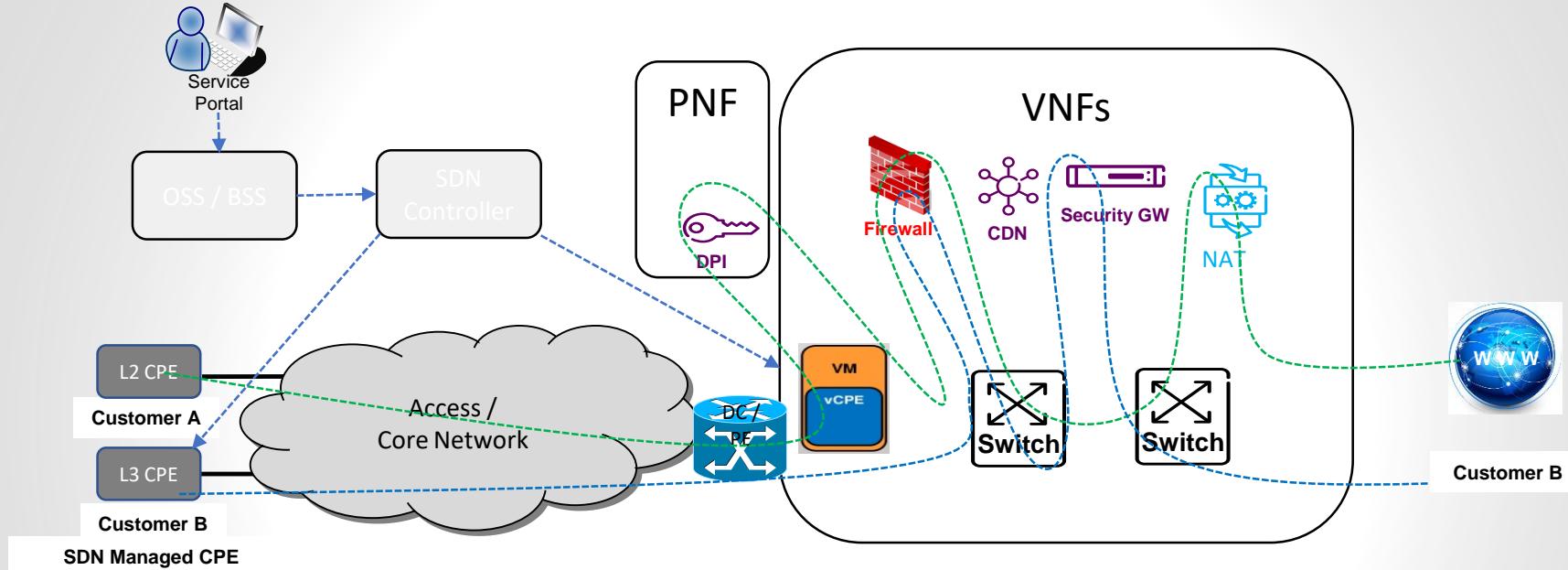
Provisioning	Telemetry	Optimisation	Automation
 <p>Topology Mapper</p> <ul style="list-style-type: none"> - Auto discovery of Network and Routes. - Specify inter-layer dependencies and Shared Link Risk Group constraints. <p>Use Cases</p> <ul style="list-style-type: none"> • Constraints-based E2E Circuit provisioning via GUI or NBI API. (eliminates human error and reduces time to provision.) 	 <p>Telemetry</p> <ul style="list-style-type: none"> - Near real-time utilization statistics. (improvement over current 5 mins sampling which is unable to pick out microbursts.) <p>Use Cases</p> <ul style="list-style-type: none"> • Traffic Analysis • Troubleshooting & Alarms • Network Change simulation • Route activities playback 	 <p>Network Optimisation (manual)</p> <ul style="list-style-type: none"> - Path Compute Engine provides suggestion for network optimization. - Segment Routing for more refined route decisions. <p>Use Cases</p> <ul style="list-style-type: none"> • Proactive monitoring of high utilization paths. • Simple activation of system suggested optimal paths. 	 <p>Automated Network</p> <ul style="list-style-type: none"> - Self-Optimising network.

Bandwidth on Demand: Scheduling through Customer Self-service Portal



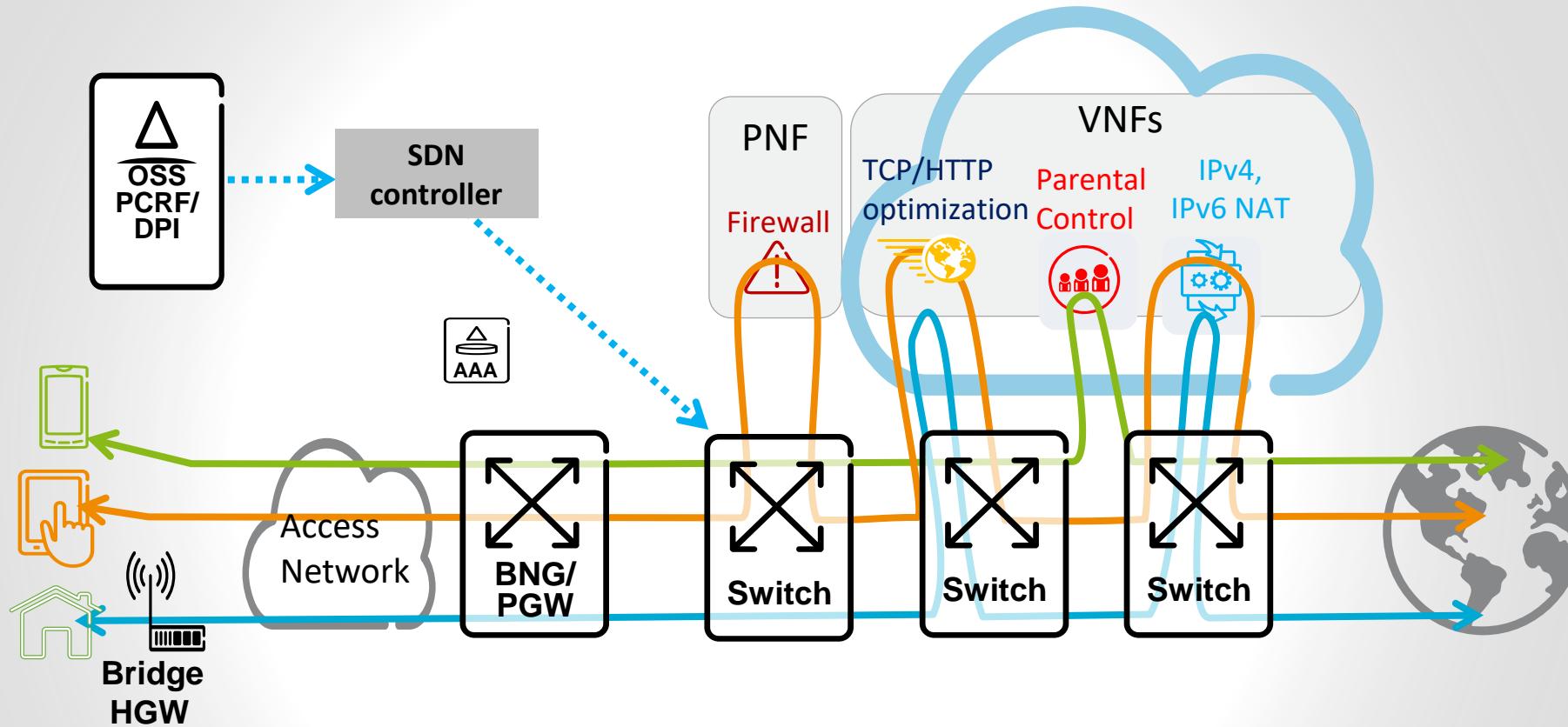
- Automated self service provisioning for Customers and Operators
- Reduces cost, provides better network control, flexibility and optimal network utilisation

Service Function Chaining: Enterprise Virtual Services



- Subscriber, application or destination based granular traffic steering
- Introduction of new functions in hours/minutes compare to weeks/months
- Automated operations, verification & troubleshooting
- Distributed dimensioning of network, leading to maximum utilization of network resources

Service Function Chaining: Consumer Virtual Home Gateway



- Enables simpler Order Management, Product provisioning and unified service assurance
- Provides real-time service execution and delivery
- Improves user experience and interaction
- Simplified home GW reduce truck rolls and provide service agility



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