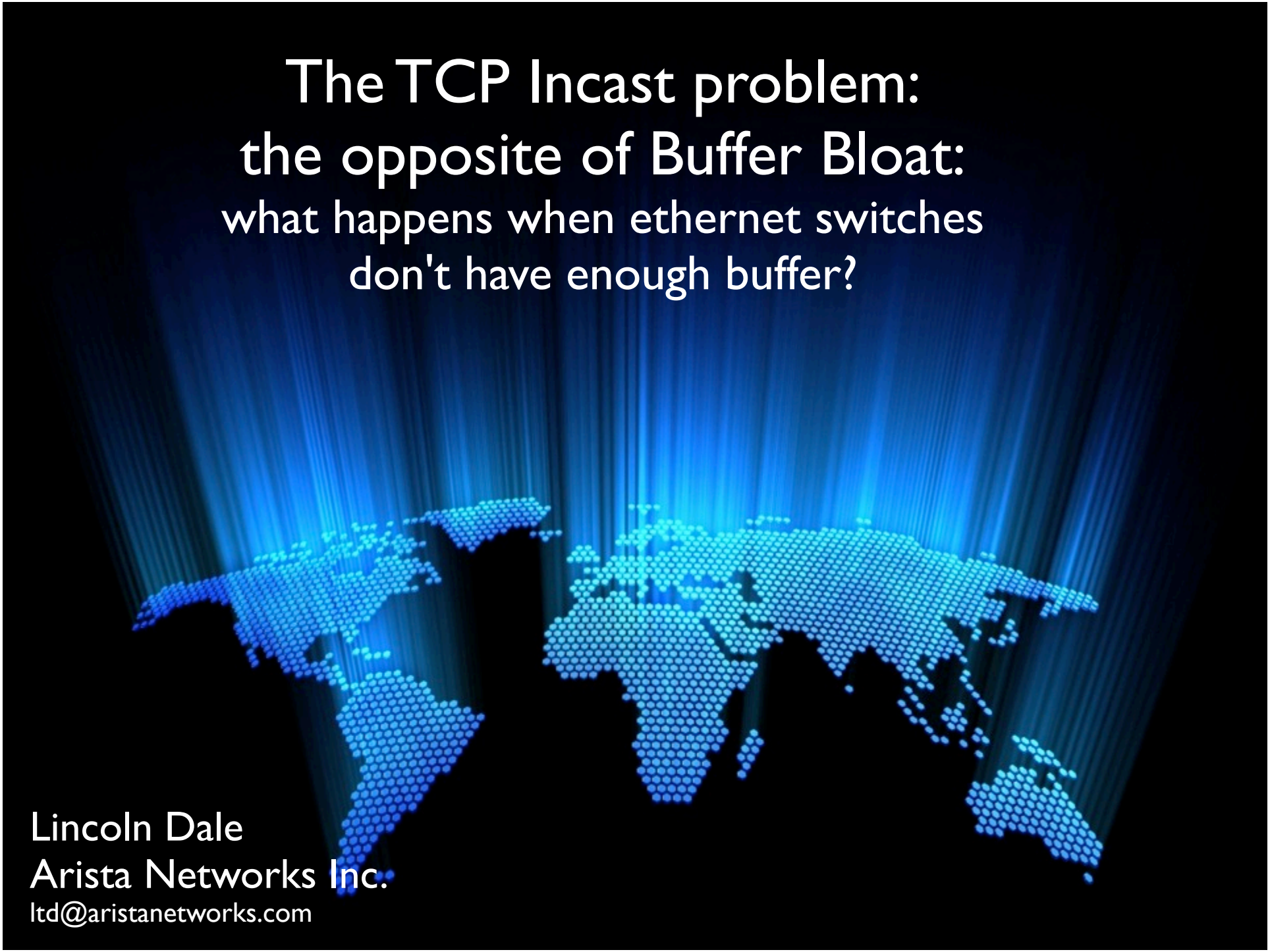
The TCP Incast problem: the opposite of Buffer Bloat:

what happens when ethernet switches don't have enough buffer?



Lincoln Dale
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ARISTA

About Arista

How large scale ‘cloud’ network designs are built

Design tradeoffs in how switch silicon is built

Simulations & Reality

Corporate Overview

- Data Center Focus
- Experienced Mgmt and World Class Engineering Team
- Award Winning Products & Differentiators
- Game changing software architecture (EOS)
- Vertical focus on Cloud Networking, HPC, financial services

Executive Team

Jayshree Ullal, President and CEO

- 50 Most Powerful People (Network World, 2005)
- 15yr SVP Cisco for Data Center, Switching, and Services
- Oversaw Catalyst 4500, 6500, and Nexus 7000

Andy Bechtolsheim, Founder, Chairman, and CDO

- Silicon Valley visionary
- Founder of Sun Microsystems
- Founder of Gig Ethernet company Granite Systems
  - Acquired by Cisco in 1996 (Became Catalyst 4xxx)
- Initial investor in Google, Inc.

The Problem with Networks Today

Single Vendor ASICs are inefficient

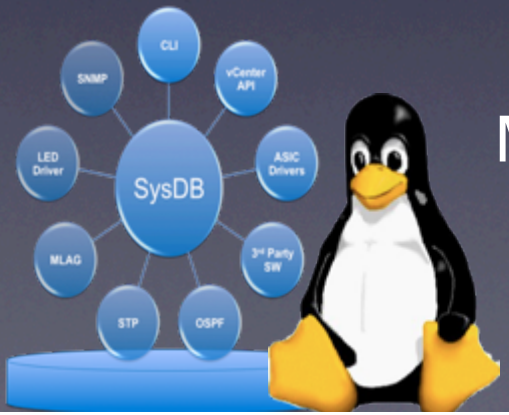
Competitive products designed for email

Network O/Ss are not open

The Arista Solution

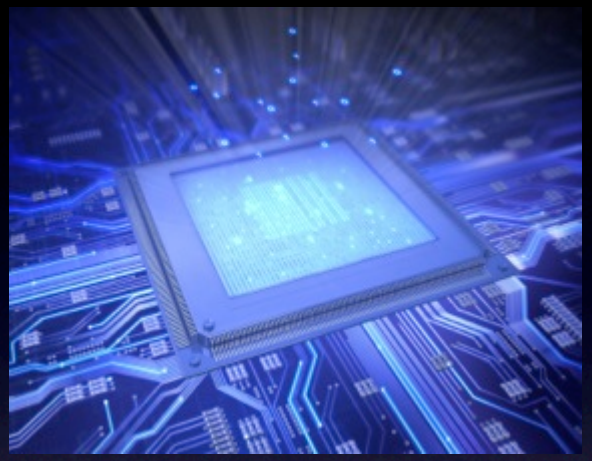
Full custom, faster, denser commercially-available silicon

Designed for data center traffic patterns

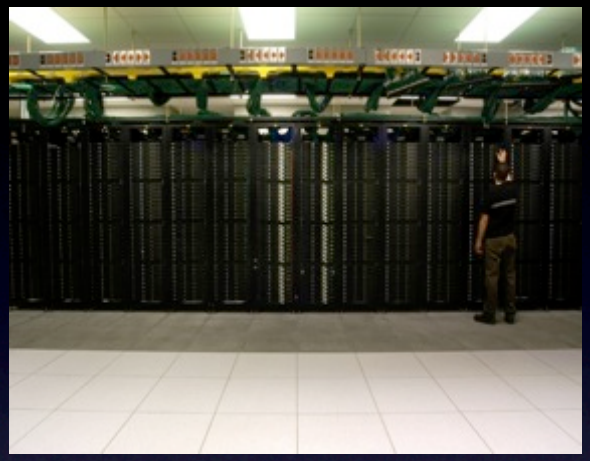


Modern, open, and scalable O/S

Strategy



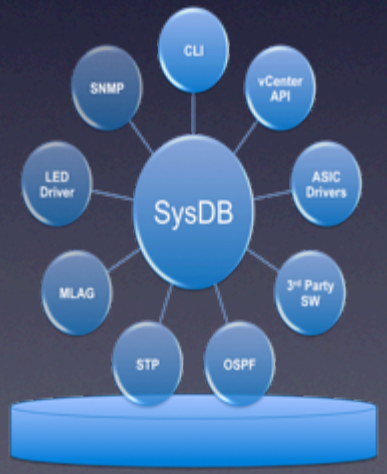
Best Full Custom Silicon Available



100% Data Center Focus

Indirect Sales & Support

Data Center Optimized Designs



Modular EOS vs Spaghetti Code

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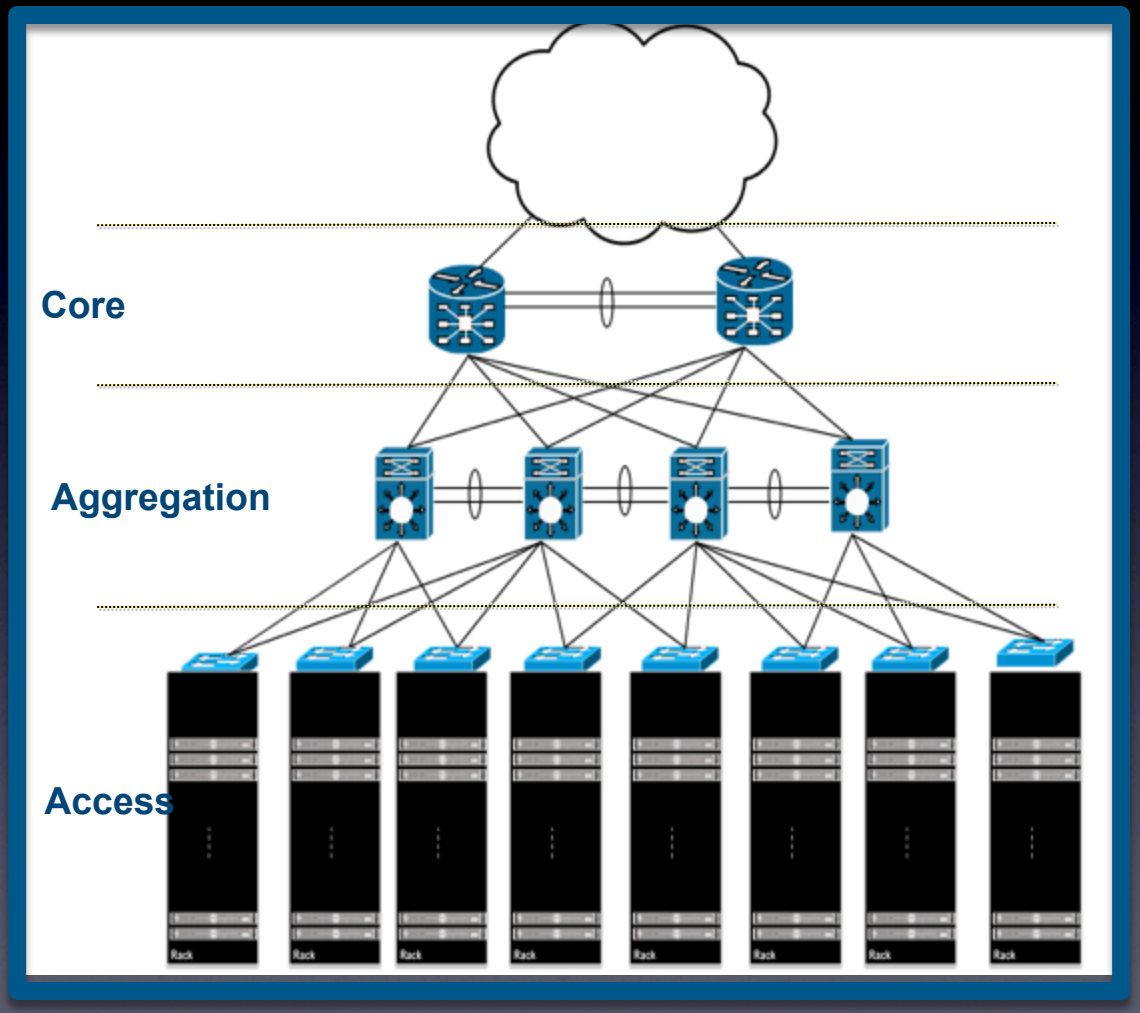
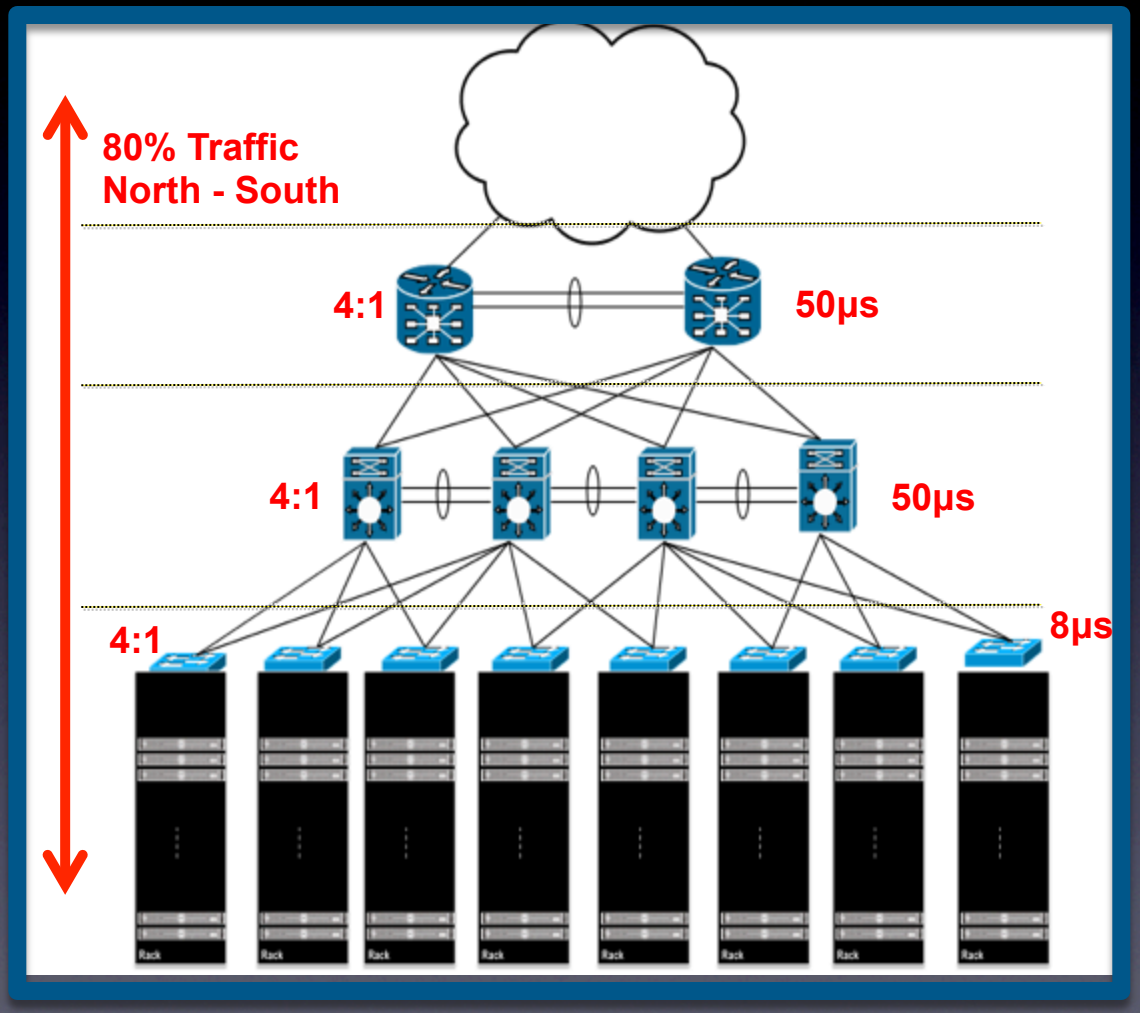
Legacy Datacenter Designs



Generic Attributes

- Mostly Client-Server Traffic
- WAN Latency impacts user experience
- Only 5 to 10% servers transmit at once
- Different architecture for different applications

Limitations of Legacy Designs



Architectural Limitations

- North-South Traffic Flow
- 64:1 to 200:1 Oversubscription
- 75 - 150µs Inter-rack latency
- 20 Racks Maximum Scaling

Requirements for Cloud/Scale-Out Architectures

Facebook:

- Low Inter-Rack Latency
- Non-Blocking Access to Cache/DB

} Optimal User Experience

Windows Azure

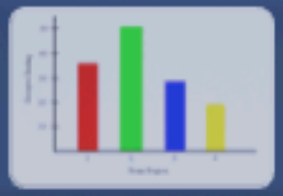
- Cloud based Compute & Storage
- Same Performance as local cluster

} Same performance as local cluster

Oil & Gas Exploration

- Non-Blocking Access
- Low Latency

} Time == Money



Hadoop

- Any-To-Any Access
- Non-Blocking

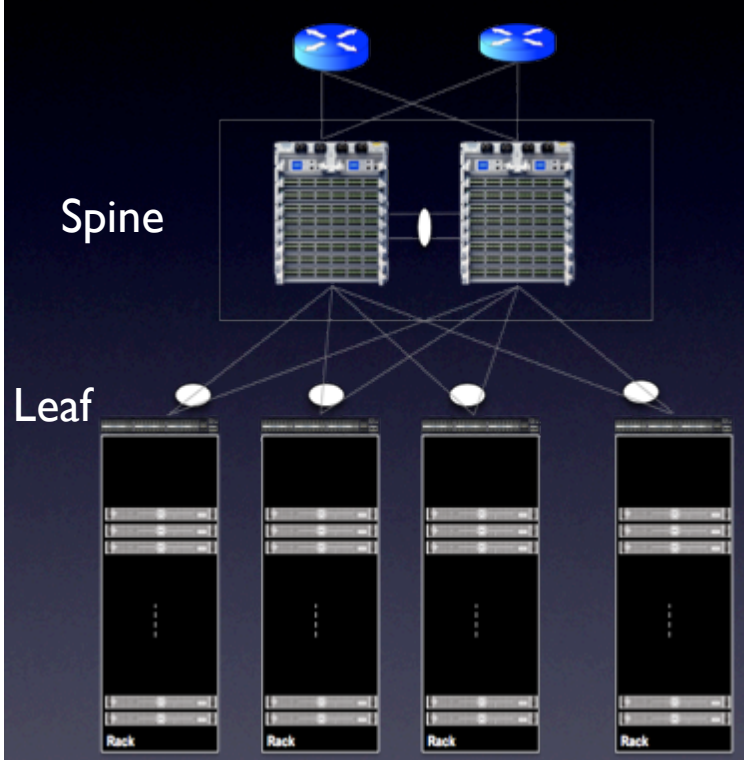
} Smart business decisions

Private Cloud

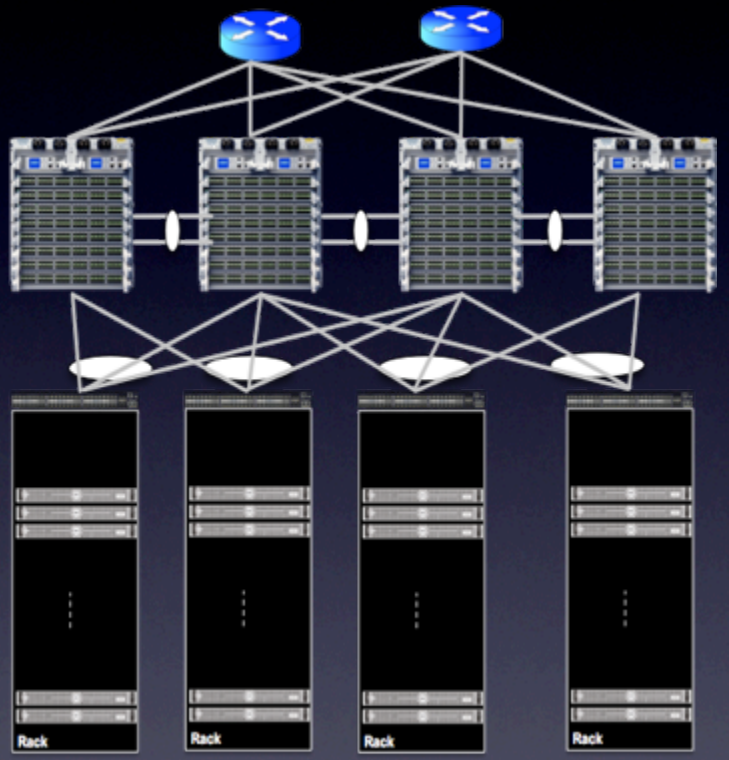
- Uniform design for all apps
- Virtualized

} Rapid service delivery

Two fundamental ways to Scale: L2 or L3

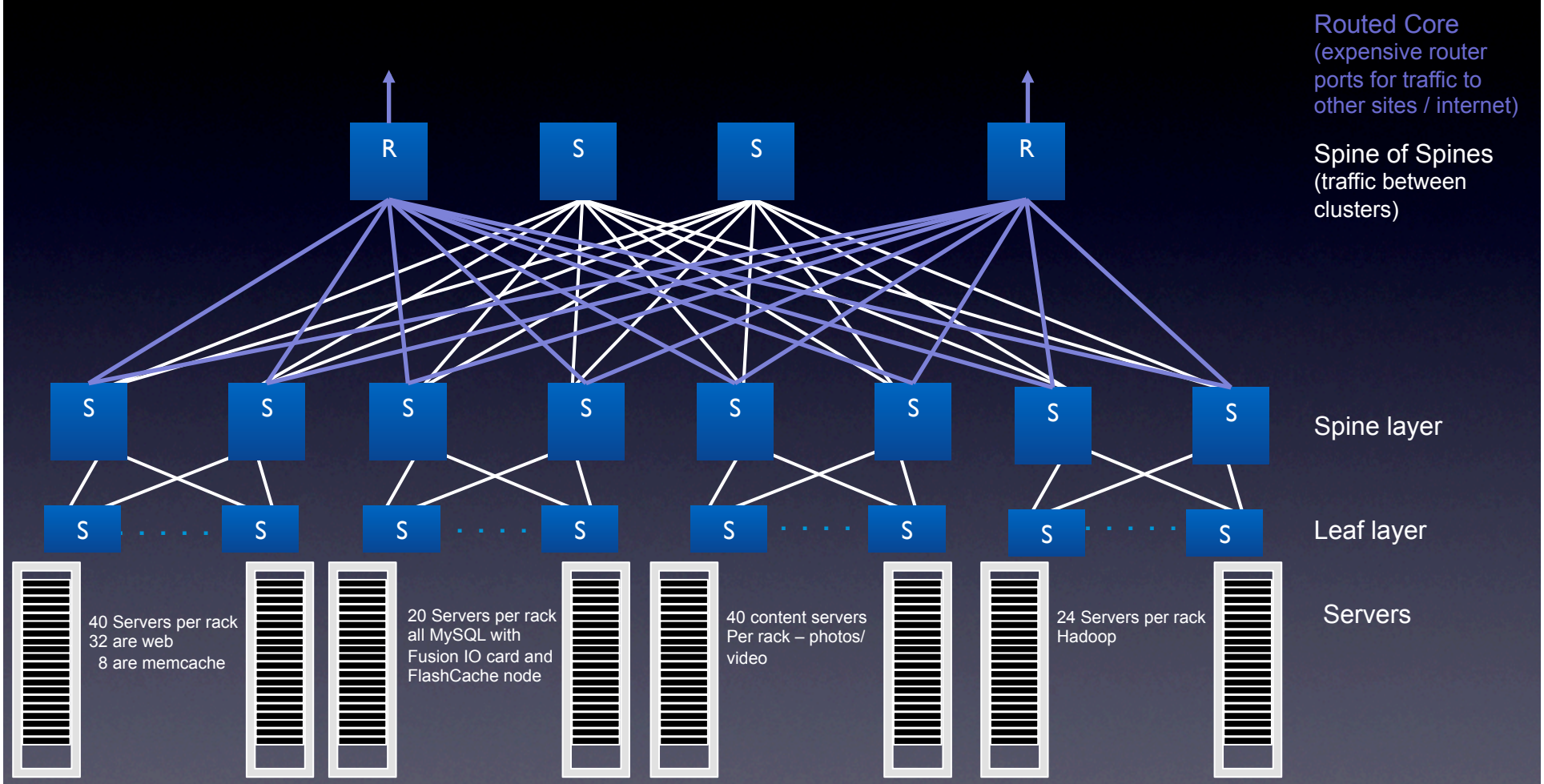


MLAG Spine (L2)
two-way active



ECMP Spine (L3 - OSPF/BGP)
today: up to 16-way ECMP

A typical Large Scale design



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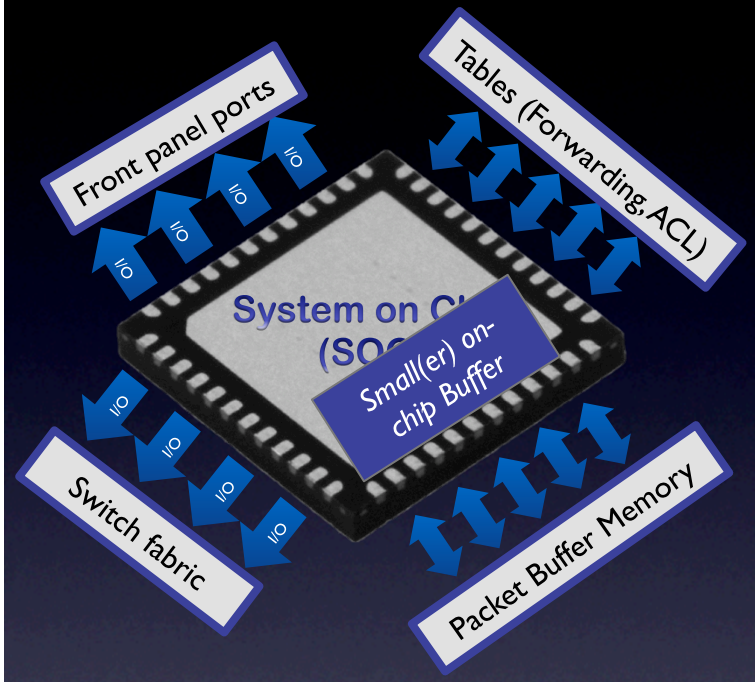
Switch silicon design – a matter of tradeoffs



Desire: put everything on a single die

Reality: Constrained by

- Size of die (cost/manufacturability)
- Power (can you cool it, reliability)
- # of pins/bumps (exotic packaging costs)
- Table sizes (larger = better)
- Feature bloat

Moore's law is helping. But it cannot change the laws of physics!

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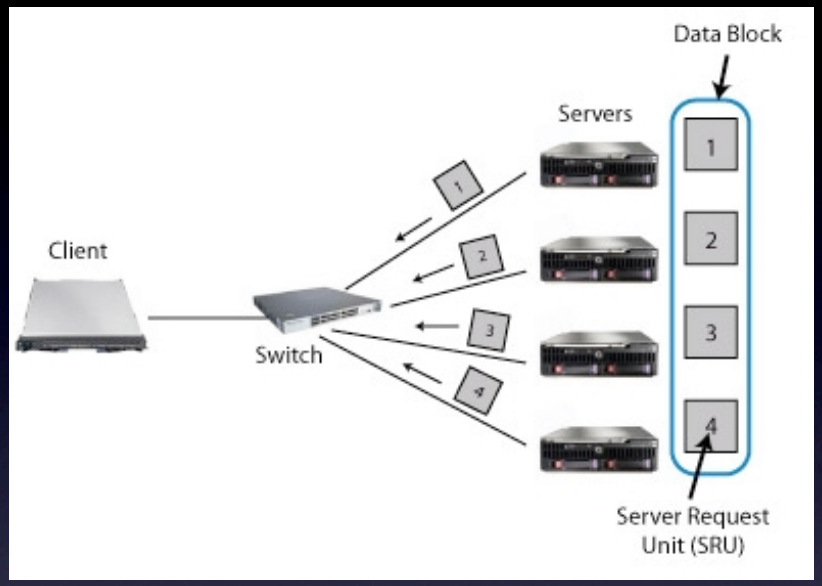
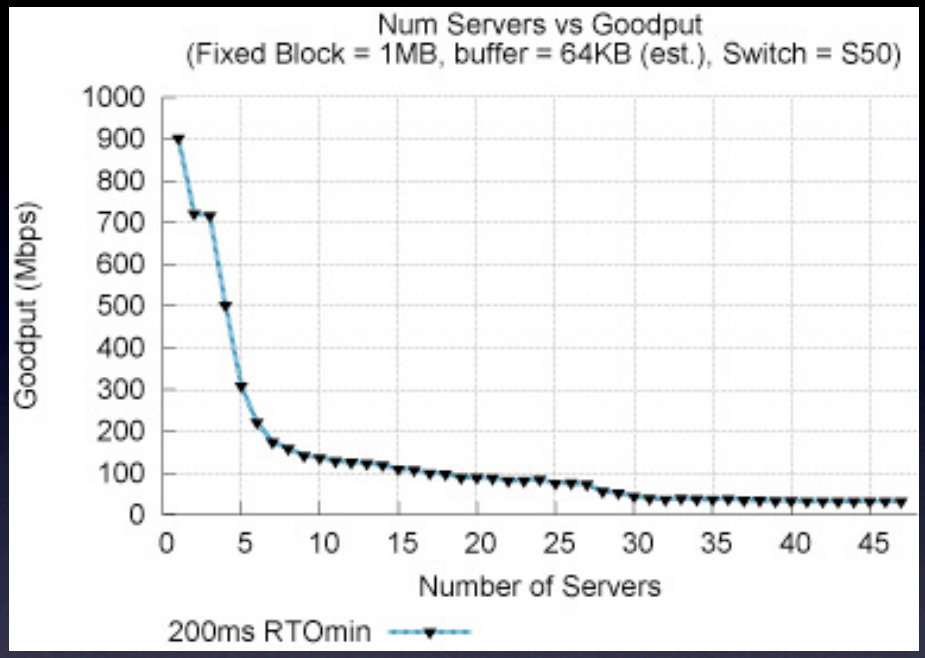
The classic TCP incast problem





Source: http://www.pdl.cmu.edu/Incast/

Simulating TCP incast on a larger scale

NS3 Network simulation tool (http://www.nsnam.org/) can be used to model real world traffic
Good paper talking about its capabilities:
http://typo3.trilogy-project.eu/fileadmin/publications/Other/Lacage-NS3.pdf

NS3 is NOT like yesterday's NS2

- It can source/sink traffic based on any number of criteria
- An accurate model of a buffered crossbar / VoQ switch can be built
- Traffic between end devices can use a real TCP stack (e.g. recent linux-2.6 kernel, FreeBSD, OpenBSD etc)
- pcap files can be generated & therefore analyzed with tools like tcptrace

Perhaps most important of all, we have proven its model is accurate.

Simulating TCP incast on a larger scale

Recreated a 'cloud' network topology with 'many to many' TCP flows

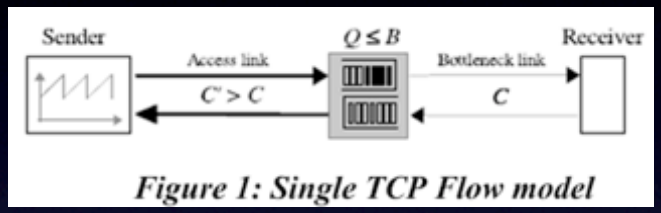


Figure 1: Single TCP Flow model

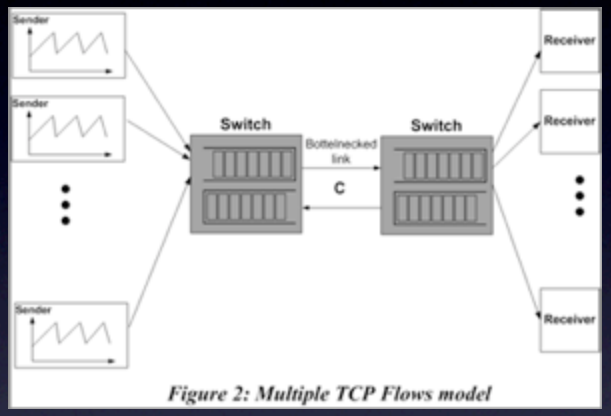


Figure 2: Multiple TCP Flows model

512 'servers' in a spine/leaf network design

- Servers attached to leaf
- 3:1 oversubscription leaf:spine (e.g. for every 12 server ports there is 4 spine links – 48:16)
- Results in 176 ports on spine with each spine dealing with Nx1533 simultaneous TCP streams/port (48 servers x 511 TCP streams x N hashed over 16-way ECMP)

NS3 model 0/3

We created two things in NS3

1. An accurate 'model' of how a switch actually works
   - Modelled on the csma-bridge.cc code included but added
   - Input buffering with virtual output queueing
   - Input buffering with 'cells' of fixed size & frame descriptors
   - Arbitration from egress to ingress (scheduling of traffic)
   - Switching latency & serialization inside-the-switch if components are based on store-and-forward
   - Most importantly of all, that an output port can only be transmitting one frame out a port at one time.
   - (the default csma-bridge code assumed there was never output congestion [even for two ports sending to one at the same time] and a frame always left the output port the same nanosecond it arrived at the input port)
2. A test harness to simulate many senders/receivers and thousands of TCP flows the exact same way you would have it for a hadoop/ bigdata type setup

NS3 model 1/3

```
int
main (int argc, char *argv[])
{
  ns3::Time::SetResolution(Time::NS); // NS

  // cubic is the default congestion algorithm in Linux 2.6.26
  std::string tcpCong = "cubic";

  // this is the default error rate of our link, that is, the the probability of a single
  // byte being 'corrupted' during transfer.
  double errRate = 0; // 0.000001;
  unsigned int runtime = 10;   // how long the sender should be running, in seconds.
  unsigned int nodes = 4;      // number of nodes
  unsigned int streams_per_node = 5;
  unsigned int mtu = 1500;    // mtu

  // the name of the NSC stack library that should be used
  std::string nscStack = "liblinux2.6.26.so";

  CommandLine cmd;
  cmd.AddValue ("TCP_CONGESTION", "Linux 2.6.26 Tcp Congestion control algorithm to use", tcpCong);
  cmd.AddValue ("error-rate", "Error rate to apply to link", errRate);
  cmd.AddValue ("runtime", "How long the applications should send data (default 120 seconds)", runtime);
  cmd.AddValue ("nodes", "number of nodes (default 48)", nodes);
  cmd.AddValue ("streams_per_node", "number of streams per node to every other node (default 10)", streams_per_node);
  cmd.AddValue ("mtu", "mtu to use (1500 default)", mtu);
  cmd.AddValue ("nscstack", "Set name of NSC stack (shared library) to use (default liblinux2.6.26.so)", nscStack);
  cmd.Parse (argc, argv);

  Config::SetDefault ("ns3::OnOffApplication::PacketSize", UintegerValue (mtu));
  Config::SetDefault ("ns3::OnOffApplication::DataRate", StringValue ("1Gbps"));

  std::cout << "LTD simulation.\n";
  std::cout << "  " << nodes << " nodes, " << streams_per_node << " streams/node, " << runtime << " runtime\n";

  // Explicitly create the nodes required by the topology (shown above).
  NodeContainer n;
  n.Create (nodes);

  // create the 'switch' in the middle
  NodeContainer csmaSwitch;
  CsmaHelper csma;
  csmaSwitch.Create (1);
  csma.SetChannelAttribute ("DataRate", DataRateValue (1000000000));
  csma.SetChannelAttribute ("Delay", TimeValue (MilliSeconds (0)));
```

NS3 model 2/3

```
// Create the csma links, from each node to the switch
NetDeviceContainer terminalDevices;
NetDeviceContainer switchDevices;

for (unsigned int i = 0; i < nodes; i++)
  {
    NetDeviceContainer link = csma.Install (NodeContainer (n.Get (i), csmaSwitch));
    terminalDevices.Add (link.Get (0));
    switchDevices.Add (link.Get (1));
  }

// Create the bridge netdevice, which will do the packet switching
Ptr<Node> switchNode = csmaSwitch.Get (0);
BridgeHelper bridge;
bridge.SetDeviceAttribute ("Mtu", UintegerValue(mtu));
bridge.SetDeviceAttribute ("Latency", UintegerValue(6000));   // 6 usec
bridge.SetDeviceAttribute ("Bandwidth", UintegerValue(1000)); // 10G
bridge.SetDeviceAttribute ("CellSize", UintegerValue (384));
bridge.SetDeviceAttribute ("CellCount", UintegerValue (409)); // 384 bytes x 4K cells = 1.5MB

bridge.Install (switchNode, switchDevices);

InternetStackHelper internet;
// The next statement switches the nodes to 'NSC'-Mode.
// It disables the native ns-3 TCP model and loads the NSC library.
//  internet.SetTcp ("ns3::NscTcpL4Protocol","Library",StringValue (nscStack));
internet.Install (n);

if (tcpCong != "cubic") // make sure we only fail if both --nscstack and --TCP_CONGESTION are used
  {
    // This uses ns-3s attribute system to set the 'net.ipv4.tcp_congestion_control' sysctl of the
    // stack.
    // The same mechanism could be used to e.g. disable TCP timestamps:
    // Config::Set ("/NodeList/*/$ns3::Ns3NscStack<linux2.6.26>/net.ipv4.tcp_timestamps", StringValue ("0"));
    Config::Set ("/NodeList/*/$ns3::Ns3NscStack<linux2.6.26>/net.ipv4.tcp_congestion_control", StringValue (tcpCong));
  }
Ipv4AddressHelper ipv4;
ipv4.SetBase ("10.0.0.0", "255.255.0.0");
Ipv4InterfaceContainer ipv4Interfaces = ipv4.Assign (terminalDevices);

Ipv4GlobalRoutingHelper::PopulateRoutingTables ();
```

NS3 model 3/3

```
  uint16_t servPort = 8080;
  PacketSinkHelper sinkHelper ("ns3::TcpSocketFactory", InetSocketAddress (Ipv4Address::GetAny (), servPort));
  ApplicationContainer sinkApp = sinkHelper.Install (n);
  sinkApp.Start (Seconds (0.0));
  // this makes sure that the receiver will run 0.5s longer than the sender application.
  sinkApp.Stop (Seconds (runtime + 0.5));

  // This sets up two TCP flows, one from A -> B, one from B -> A for each node
  for (unsigned int i = 0; i < nodes; i++)
    {
      for (unsigned int j = 0; j < nodes; j++)
        {
          if (i != j)
          {
             for (unsigned int k = 0; k < streams_per_node; k++)
             {
               Address remoteAddress (InetSocketAddress (ipv4Interfaces.GetAddress (i), servPort));
               OnOffHelper clientHelper ("ns3::TcpSocketFactory", remoteAddress);
              clientHelper.SetAttribute ("DataRate", DataRateValue (DataRate ("1Gbps")));
              clientHelper.SetAttribute ("PacketSize", UintegerValue (1460));
               clientHelper.SetAttribute ("OnTime", RandomVariableValue (ConstantVariable (1)));
               clientHelper.SetAttribute ("OffTime", RandomVariableValue (ConstantVariable (0)));
               ApplicationContainer clientApp = clientHelper.Install (n.Get (j));
               clientApp.Start (Seconds (0.2));
               clientApp.Stop (Seconds (runtime));
             }
          }
        }
      }

  // This tells ns-3 to generate pcap traces.
  std::stringstream fname;
  fname << "ltd_" << runtime << "_" << nodes << "x" << streams_per_node << "_" << mtu;
  csma.EnablePcapAll (fname.str(), false);

  AsciiTraceHelper ascii;
  //csma.EnableAsciiAll (ascii.CreateFileStream ("ltd.tr"));

  Simulator::Stop (Seconds (runtime + 2));
  Simulator::Run ();
  Simulator::Destroy ();

  return 0;
}
```

Simulating TCP incast on a larger scale

# simutaneous TCP connections	# ports	Peak buffer utilization (ingress buffer)
20K	16 ports	1.74 MB/port
50K	100 ports	3.66 MB/port
120K	200 ports	~3.54 MB/port
300K	400 ports	7.55 MB/port

Simulating 512 'servers' in a spine/leaf network design

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A typical 'cloud' / 'social networking' / 'search engine' has >100K TCP flows/ server.

- >4.8M TCP flows seen by each spine switch downlink port to leaf switch!

Real world buffer utilization

Real World Data	Customer	Real Buffer Utilization Observations	Max Buffer Used
	HPC	Storage Cluster – Medium	33 MB
	Animation	Storage Filer (NFS)	6.2 MB
	Software vendor	Engineering Build Servers (Perforce)	14.9 MB
	Online shopping	Hadoop 2K servers – Big Data	52.3 MB
	Educational	Enterprise Data Center (Virtualization)	52.4 MB

10MB = 1msec buffer @ 10G

This is real world data we have seen from production spine switches.

Switch silicon keeps a high-water-mark record of maximum VoQ buffer utilization for buffering to an output port

Reality: buffers DO matter

ARISTA

Thank You!