

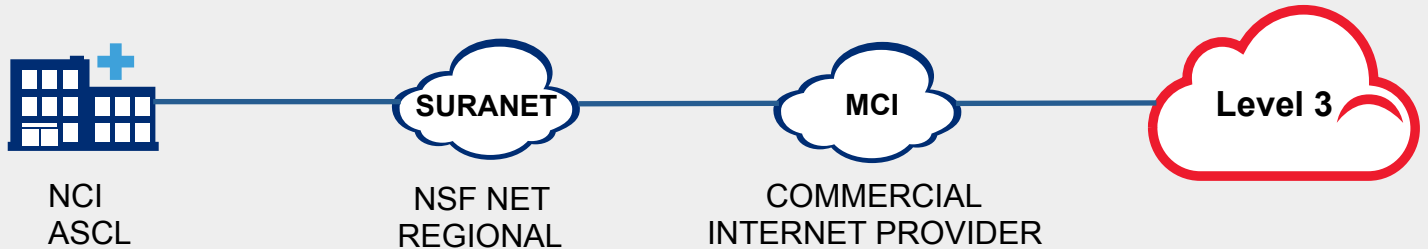


Challenges If They Were All Just Technical

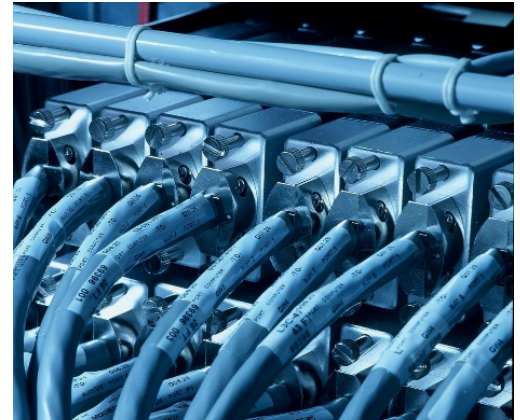
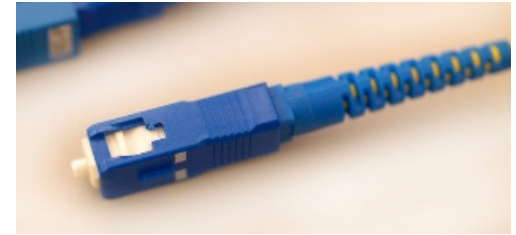
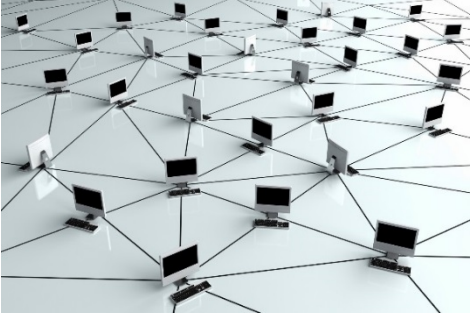
Jack Waters

Chief Technology Officer
Level 3 Communications

My Internet Path



Technical Challenges





SOCIETAL

PEOPLE

Incentive Challenges

POLITICAL

**BUSINESS
SELF-INTERESTS**



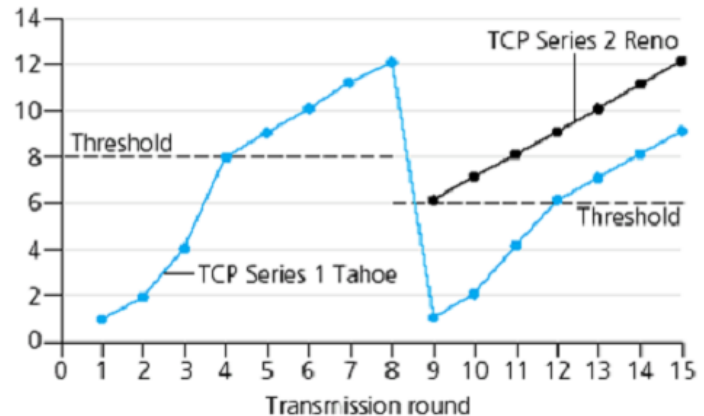
What we used to worry about . . .

Congestion Avoidance and Control

- In Oct '86, NSFNET experienced congestion collapse
- TCP Tahoe... slow start, congestion avoidance, fast retransmit, timeout detection
- TCP Reno . . . Tahoe with the addition of Fast Recovery



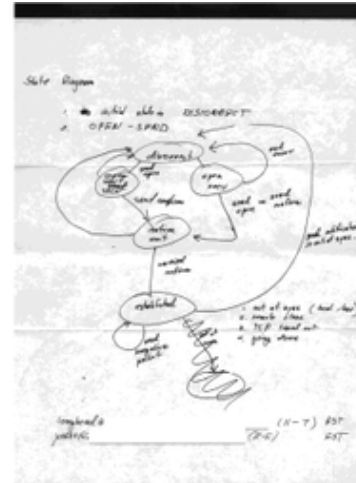
Source: Sharkfest '10; <https://blog.wireshark.org/wp-content/uploads/2010/06/Van-Jacobson1.jpg>



Source: <http://jsun.iteye.com/blog/2055939>

BGP

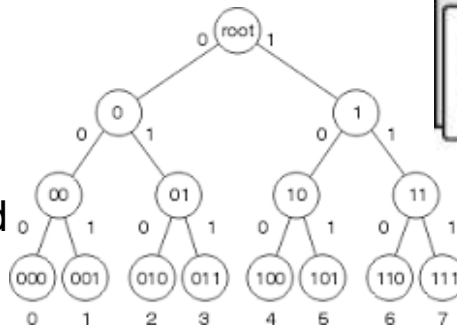
- NSFNET Backbone Phase 1, pushing the limits of scale
 - Multihoming
 - Loop Prevention
 - EGP Scale
- “Three Napkin” lunch in 1989 at IETF12
 - BGP4 still in use on the Internet today
 - Many additions for CIDR, i-BGP, Route Reflection, etc.



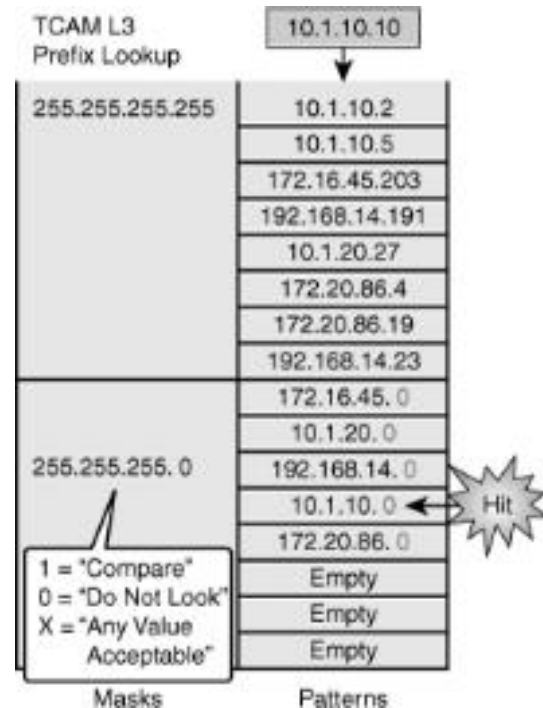
Source: *BGP Routing Policies in ISP Networks*, Matthew Caesar and Jennifer Rexford

Switching and Lookup Speeds

- In the '90s some routing infrastructure exceeded the capabilities of processor switching in software
- More efficient route lookup algorithms and caching bought us time
- OC48 speeds required hardware forwarding
- Use of content addressable memory and other hardware assist begins



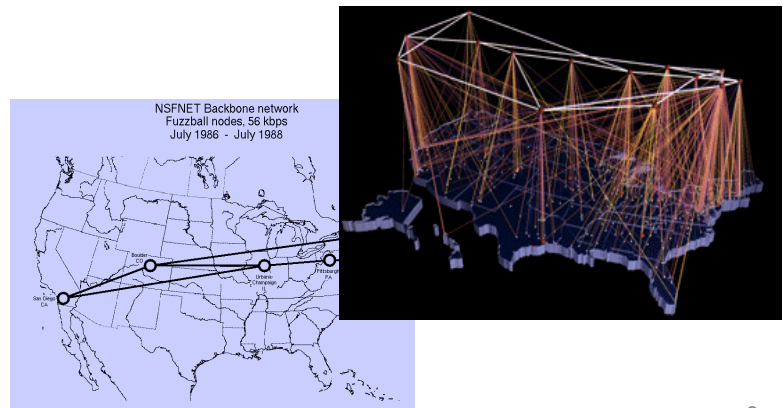
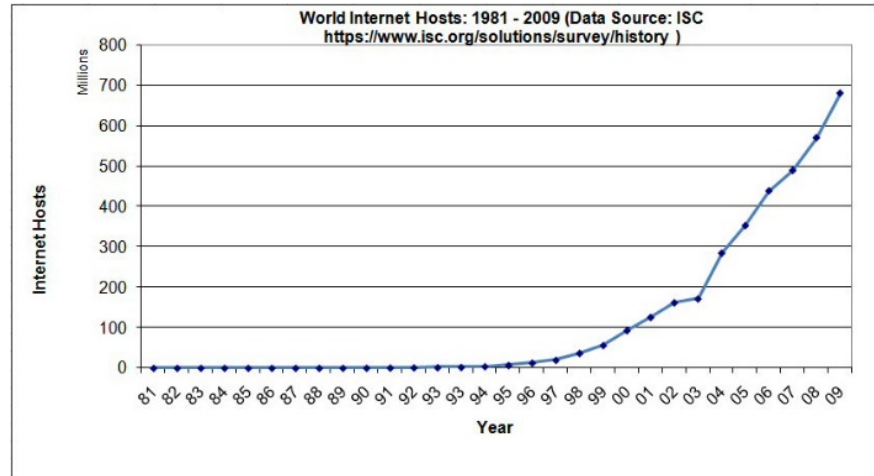
Source: <http://www.cisco.com/c/dam/en/us/support/docs/ip/express-forwarding-cef/13706-20c.gif>



Source: http://ciscodocuments.blogspot.com/2011/05/chapter-4-implementing-inter-vlan_20.html

Keeping Up with Demand

- Internet growth outpacing router density, capabilities
- Network scale and fragility
 - Complicated core topologies
 - Edge multiplexing (frame)
 - Adjacency growth
- Capacity scale and traffic engineering overlays
 - Subrate – T1s to T1s to T3s
 - Frame/ATM vs. POS
 - POS/IP vs. MPLS-TE



Many complex problems have been solved using technology

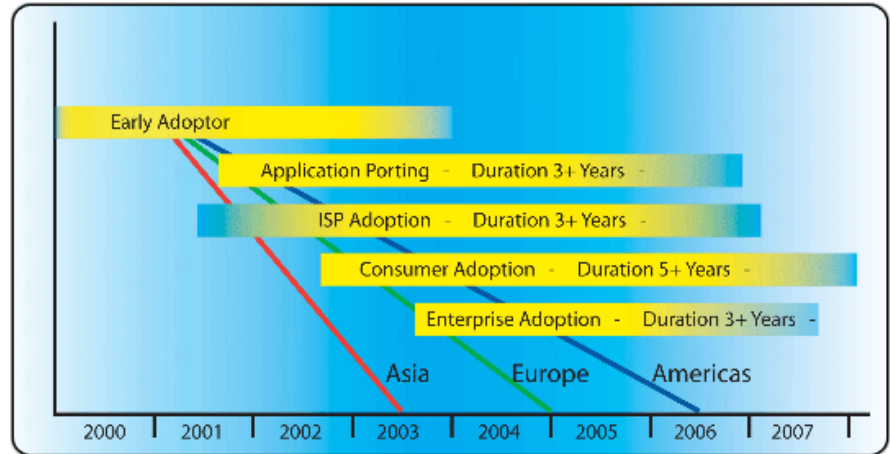


**Congestion
Route Propagation
Switching and Lookup Speeds
Hyper Growth and Scale**

But some problems we struggled with...

IPv4 Address Exhaust

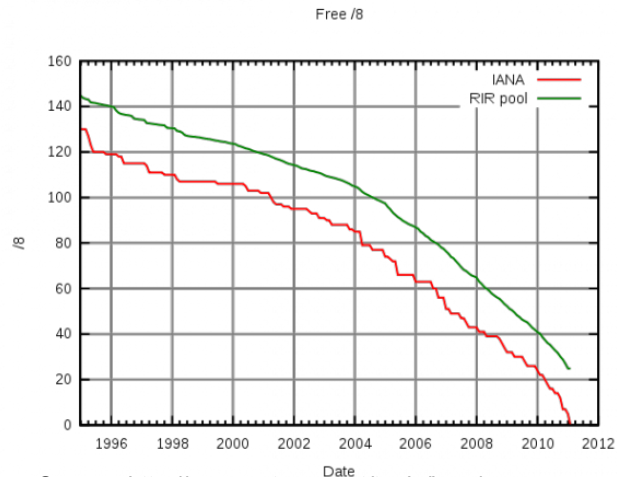
- Not from lack of foresight...work began in 1993 when only a ¼ of IPv4 space was consumed
- Not just larger address space; IPsec compliance, flow label, extensibility



Adapted from Source: IPv6 Timeline A pragmatic projection <http://www.nanog.org/mtg-0302/ppt/hain.pdf>

Technology problems largely solvable but ...

- No real incentive existed
- Scarcity not enough motivation as long as there are patchwork solutions available



Security

- The Internet: open, ubiquitous, anonymous, and addressable
- Attacks on infrastructure - Man-in-middle; TCP hijacking, protocol vulnerabilities, SYN attacks, DDoS
- The 2600 Hack – Circa 1971
- The Morris Worm – Circa 1988

Technology problems largely solvable but ...

- Fundamental architecture has a bit of a flaw
- Incentives and motivation unclear
 - Consumers
 - Enterprises
 - Network Providers

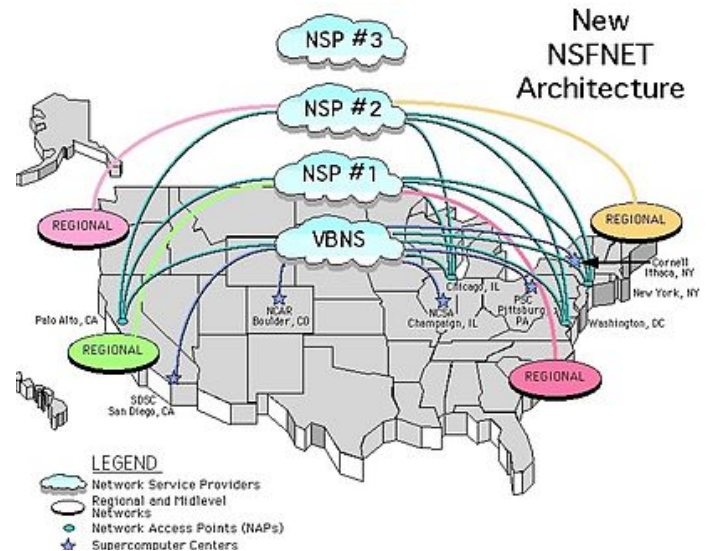


Interconnection

- Federal Internet Exchanges... Network Access Points (NAPs)... Direct Interconnection
- Interconnection participation model (i.e., informal)
- Route-servers, BGP scale, route-registries
- Shortest-exit (IGP inferred) vs. Best-exit (MED)

Technology problems largely solved or solvable but...

- Market forces and competitive behavior
- Content (War and Peace) vs. Eyeballs (Dial-up)
- Incentives and motivation unclear



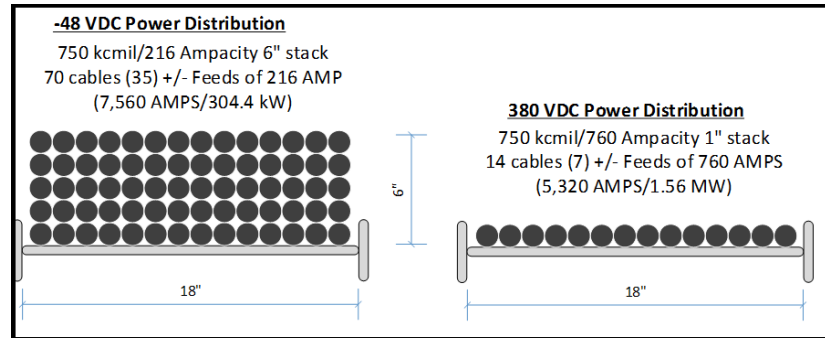
Source: https://en.wikipedia.org/wiki/Network_access_point



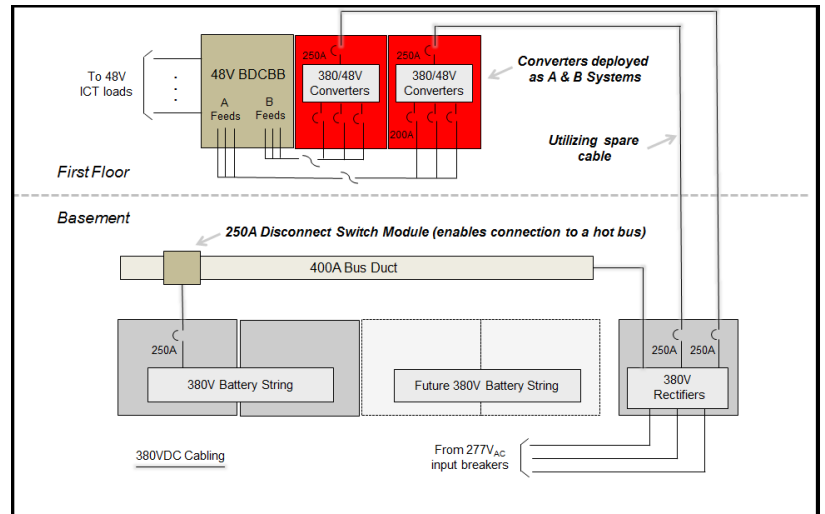
What we worry about today. . .

Power, Space and Cooling

- Increasing energy costs – we need to improve PUE
- Increasing watt/sq.ft. power draw – improved watt/Gbps efficiency; but absolute draw problematic
- Legacy facility air cooling and power plant distribution
- 380v DC power plants
- Containment and closed-loop cooling



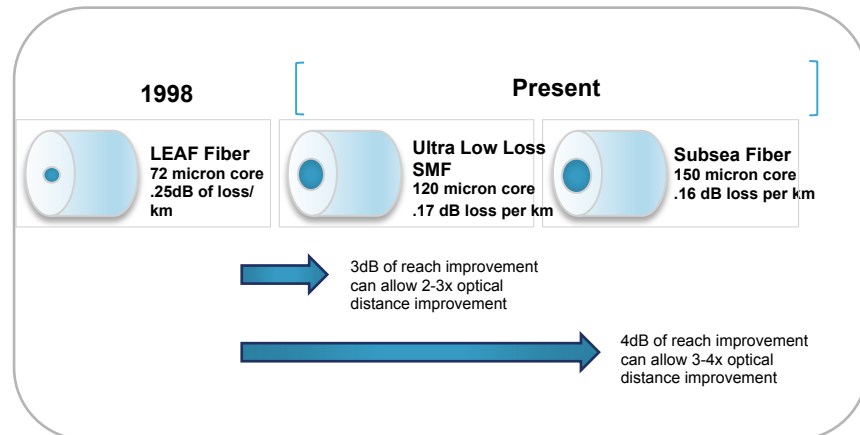
Source: Level 3 Communications



Source: Level 3 Communications

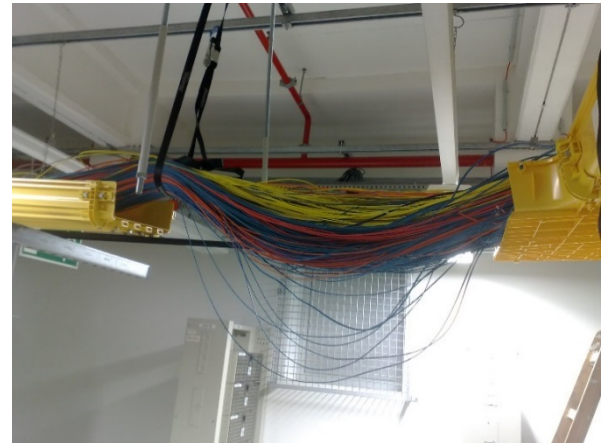
Fiber Technology Has Changed a Lot

- In the '90s the first strategy was plastic pipes
- In the late '90s the big break through in fiber was Large Effective Area Fiber NZDSF
- Loss characteristics of fiber have improved since our last major intercity build 15 years ago
- Larger effective areas may be able to be used for terrestrial applications



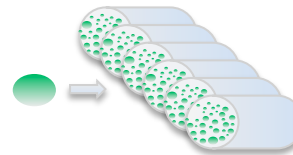
100G Technology

- Leverage 100G technology
- As an industry, we have become experts in
 - Link Aggregation
 - Equal Cost Multi-Path
- But it got too difficult
- Lots of links, problems with flow sizes
- Simplified operation, improved performance, lower cost
- 200G and 400G on horizon but with limited reach



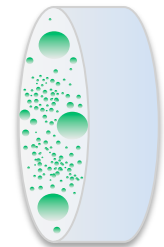
Benefits of 100G

N x 10G



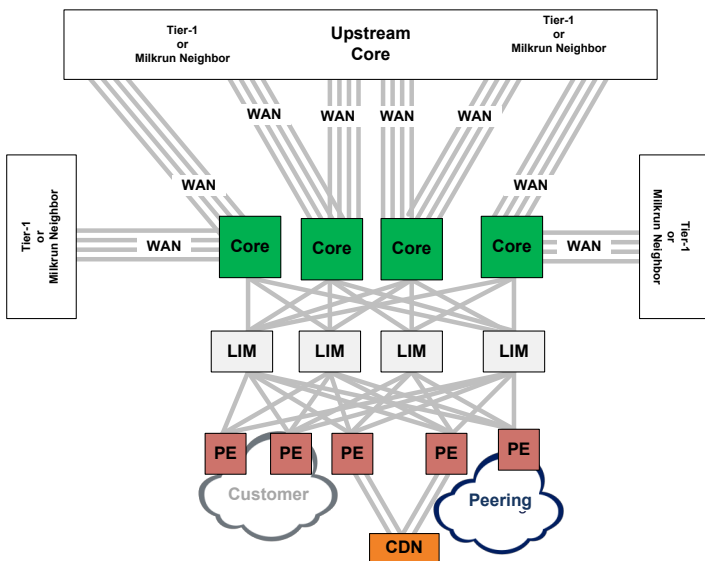
Large flows have a high probability of being put onto a link that will overflow and drop packets

100G

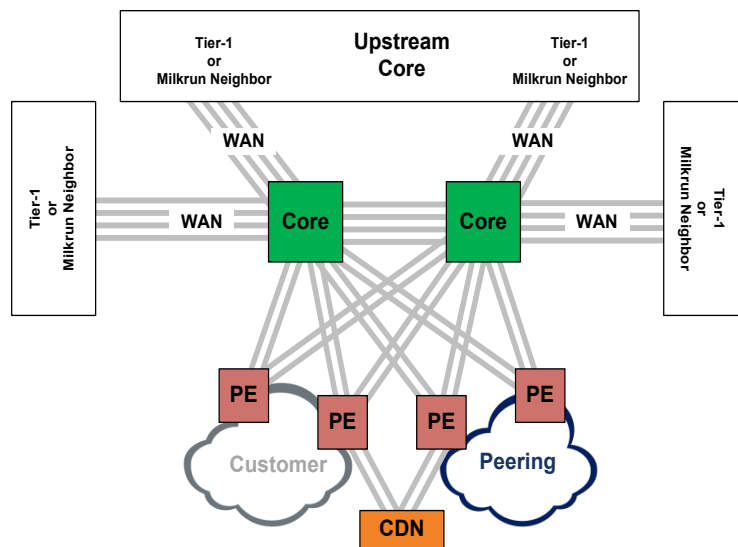


Large flows don't put other traffic at risk

3-Stage CLOS



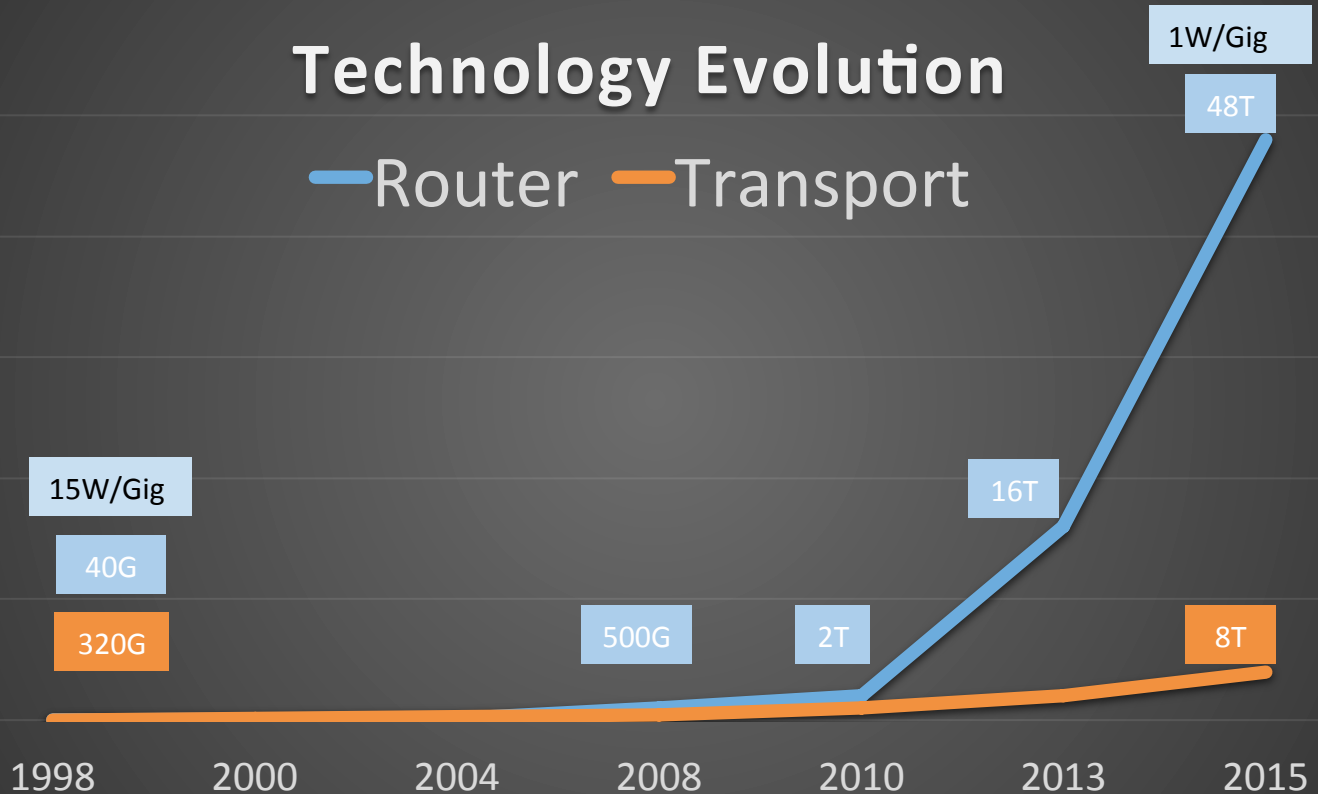
Spine/Leaf



Source: Level 3 Communications

Technology Evolution

— Router — Transport

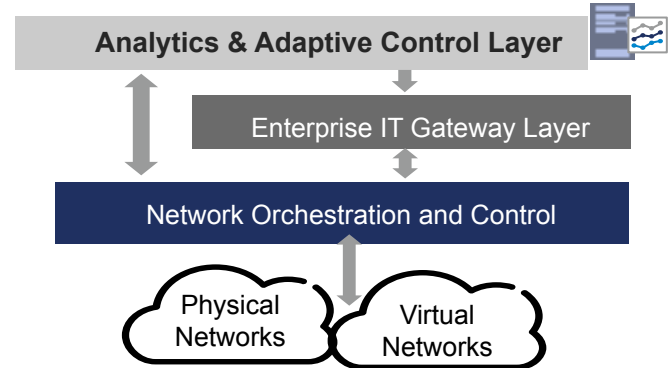


Source: Level 3 Communications

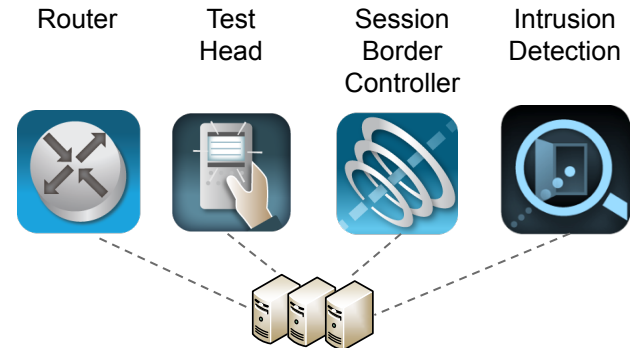
Control and Automation

- Eliminating direct human interaction with heterogeneous network elements; human error-rate
- Installation intervals longer than need be, largely due to human factor
- Operational scale
- Software Defined Networks and Network Function Virtualization

Software Defined Networking (SDN)



Network Function Virtualization (NFV)

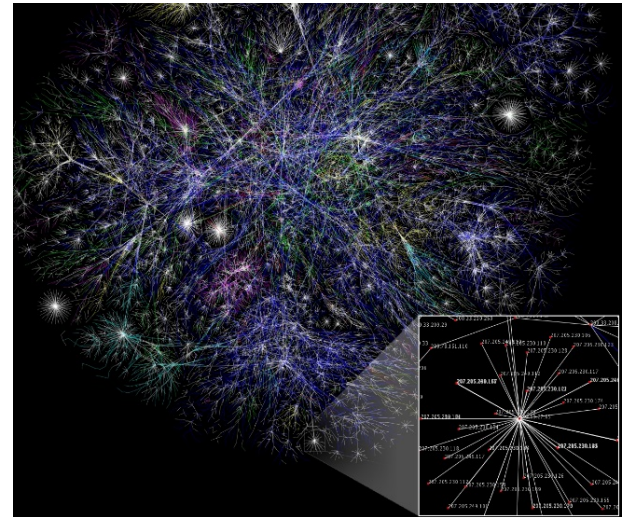


Interconnection

- Regulation – Growing regulatory interest in Internet Interconnection
 - US Open Internet Order
 - EU Internet Order (perhaps)
- Changing Internet peering dynamics
- Ratios, bit-miles, longest-exit, localized-interconnection
- What's the incentive to fix interconnection?



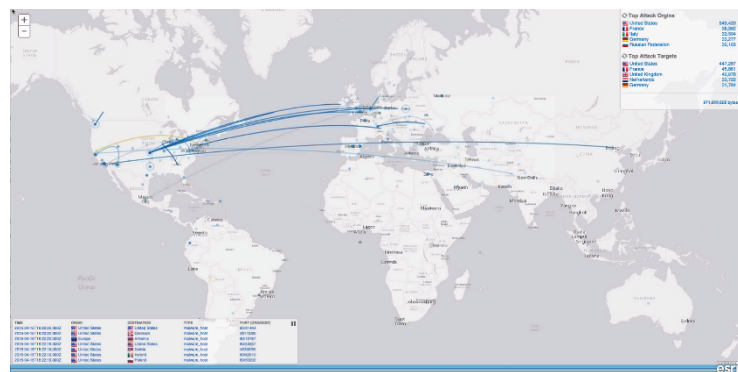
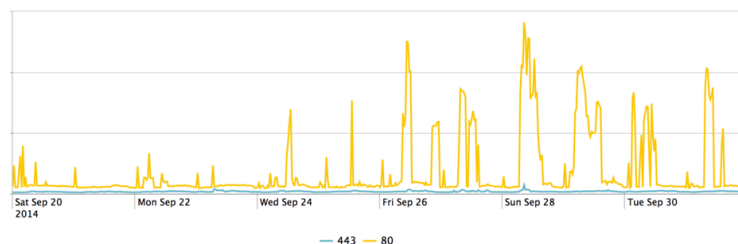
Source: NPR: FCC Approves Net Neutrality Rules For 'Open Internet,' February 26, 2015



Security

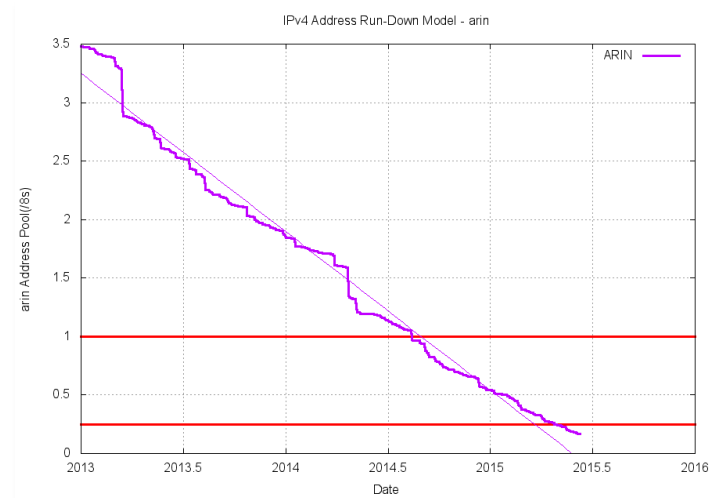
- Transition from exuberant geeks to nation state and organized crime actors
- The amplification effect; host count growth created enormous opportunity for exploitation (botnets, etc.)
- Good vs. Bad traffic; DDoS and access attacks disguised as legitimate traffic. Blocking all DNS or NTP traffic is not practical
- BGP prefix hijacking; AS origin authenticity
- What's the incentive to fix security?

Shellshock

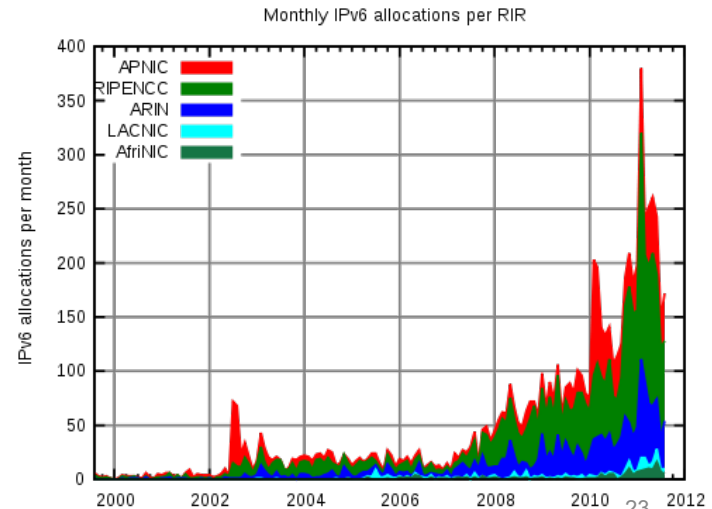


IPv4 Address Depletion


- ARIN out of IPv4 address space today
- 90%+ of traffic still using IPv4
- Growth of Secondary IPv4 Market
 - Online auction
 - Private transaction
- IPv6 adoption is picking up
 - 100% traffic growth each year
 - Traffic growth from 5% - >10% in 2015
 - Barrier - knowledge, understanding
- What's the incentive to adopt IPV6?



Source: Geoff Huston



Source: NetworkWorld: Measuring IPV6 Growth, Scott Hogg, Nov. 21, 2011,



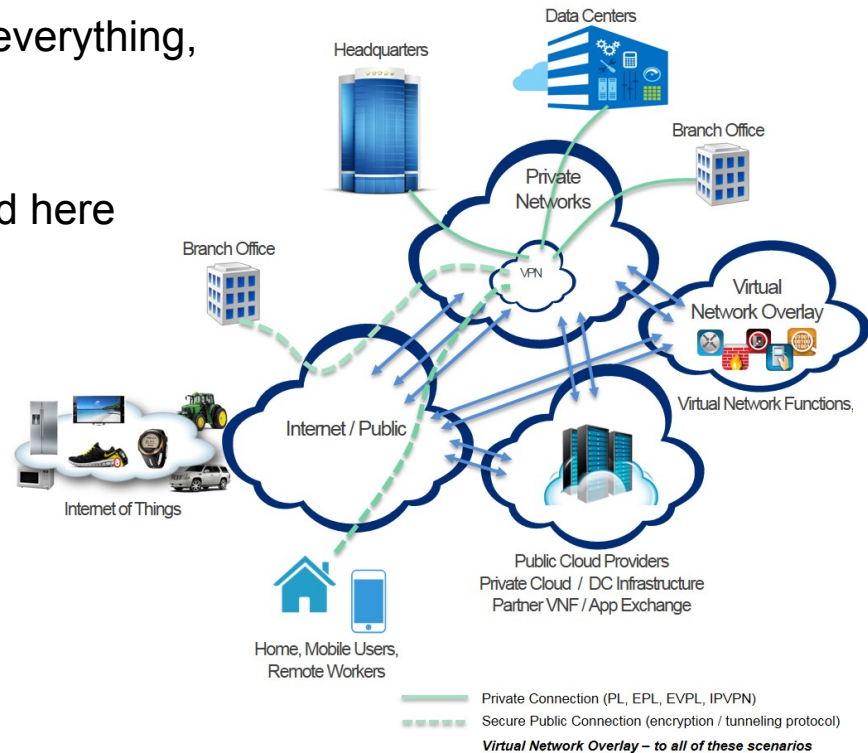
**The industry continues to solve the technology challenges...
...and I wouldn't ever bet against that**



But here's what I worry about for the future...

Most Obvious Statement Warning:

- EVERYTHING, and I mean everything, can be carried over IP
- Notice there is no time bound here
- Whether it's public or private
- Depends on solving the incentives challenges:
 - Security
 - Interconnection
 - Adoption of IPV6



Source: Level 3 Communications

