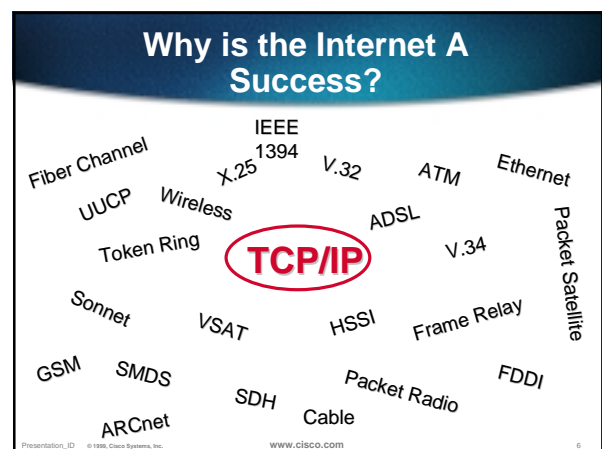
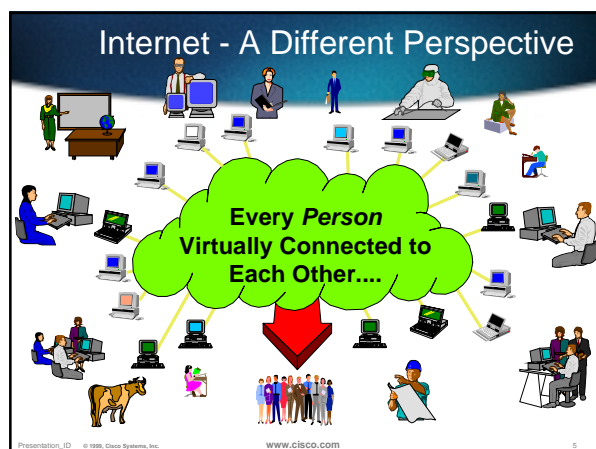
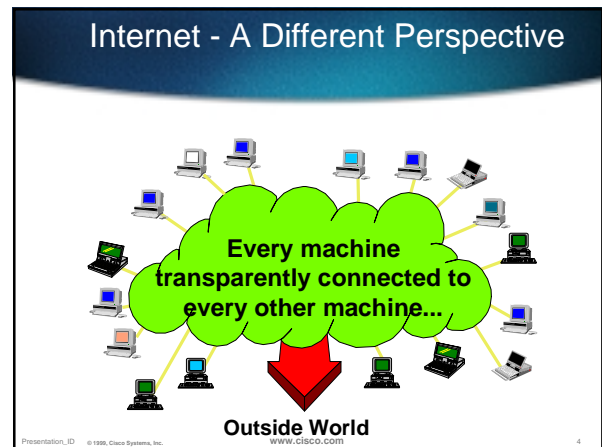


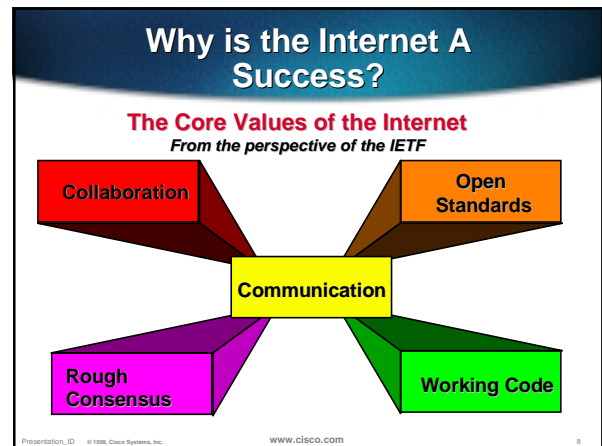
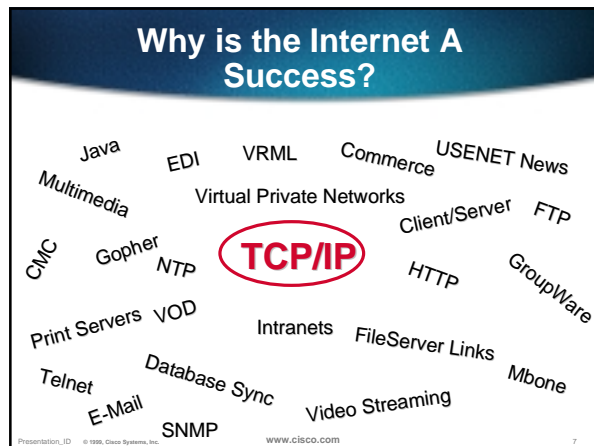
Who is Barry?

- **Barry Raveendran Greene**
 - ✓ bgreene@cisco.com
- **CTO Corporate Consulting**
- **Working on networks for the past 21 years.**
 - ✓ Airfield and Military systems for the first decade (including the ARPANET and MilNet)
 - ✓ Internet Specific for the past decade

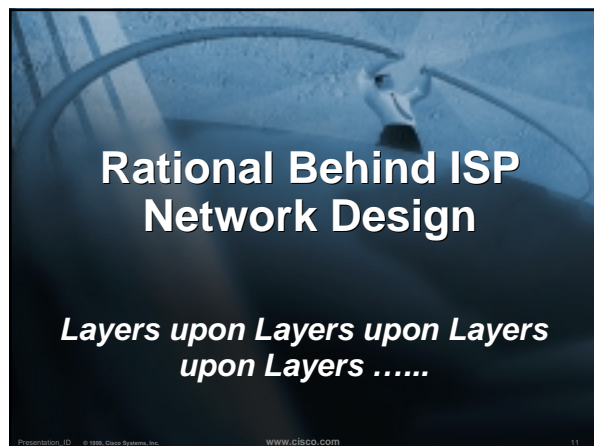
Current Specializations

- **Building, Running, Scaling, and Making Money in the ISP Business**
- **Content Networking**
- **ISP Routing**
- **ISP Security**
- **Internet eXchange Points (IXPs)**
- **Trans-Oceanic Backbones**





- ## Agenda
- Rational Behind ISP Network Design
 - Point of Presence Topologies
 - Adding Services to the Architecture
 - Impact of Services on the Network
- Presentation_ID © 1998, Cisco Systems, Inc. www.cisco.com 10



The Free On-line Dictionary of Computing

Architecture: Design; the way components fit together; it may also be used for any complex system, e.g. “software architecture”, “network architecture”

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Network Design and Architecture...

- ... can be critical
- ... can contribute to the success of the network
- ... can contribute to the failure of the network

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Ferguson's Law of Engineering

No amount of magic knobs will save a sloppily designed network

Paul Ferguson—Consulting Engineer,
Cisco Systems

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What Is a Well-Designed Network?

- One that takes into consideration some main factors
 - ✓ Topological/protocol hierarchy
 - ✓ Redundancy
 - ✓ Addressing aggregation (IGP and BGP)
 - ✓ Scaling
 - ✓ Policy implementation (core/edge)
 - ✓ Management/maintenance/operations
 - ✓ Cost

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One Must Acknowledge that...

- Two different worlds exist
 - ✓ One world revolves around private organizational networks and another concerns the global Internet
- Growth in the Internet is faster than any other technology introduced to the public-at-large

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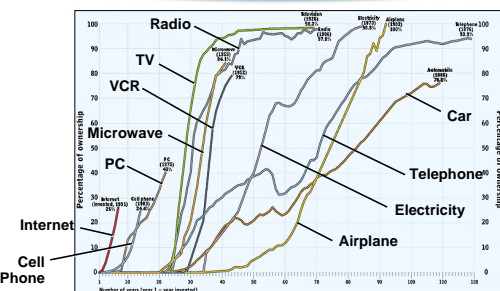
Scaling is the #1 Problem on the Internet

If you're not scared yet, you don't understand the problem!

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Technology Adoption



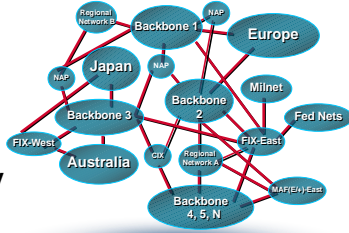
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Basic Scaling Concepts

- Hierarchy
- Discipline
- Information reduction
- Consistency
- Planning



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Old World vs New World

More Issues to Consider

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Key Design Principles

• Internet/L3 Networks

- ✓ Build the redundancy into the system.

VS

• Telco Voice and L2 Networks

- ✓ Put all the redundancy into a box.



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Key Design Principles

• Internet Years

- ✓ Very Rapid Change
- ✓ 1 Year = 3 Months

VS

• Telco Years

- ✓ Slow Consistent Change
- ✓ 1 Year = 3 Years

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Key Design Principles

• Internet Growth

- ✓ + 100% per year for the past 10 years

VS

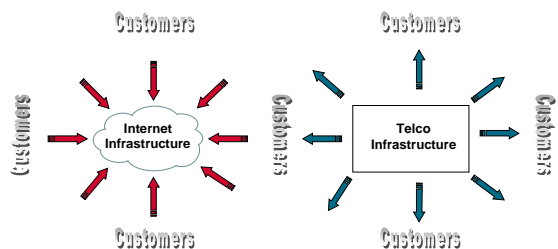
• Telco Growth

- ✓ Telephony is 5% to 25% year for the past 10 years

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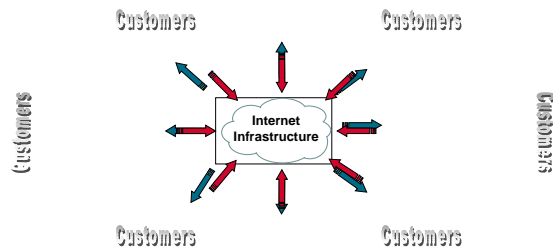
Key Design Principles



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Key Design Principles



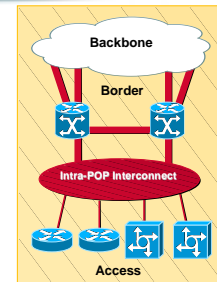
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Key Design Principles

• Triple Layered POP Redundancy

- ✓ Two connection to the backbone from any boarder router.
- ✓ Two boarder routers, load balanced w/ one able to take the full load.
- ✓ Two POP interconnect devices and/or a physical failover medium (FDDI or POS)



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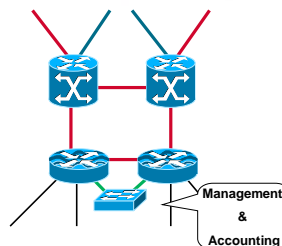
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Key Design Principles

• Interconnection for Management, Security, and Accounting services

- ✓ Netflow Devices - FlowCollector
- ✓ Syslog collector for all network devices
- ✓ SNMP collector (PC Based UNIX)
- ✓ Security Auditing Tools (NetSoner)



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Key Design Principles

“ Do not throw out the baby with the bath water. +100 years of build networks is experience that cannot be ignored. ”

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Core Influences to ISP Design

- Modular Design
- Functional Design
- Tiered/Hierarchical Design
- Multiple Levels of Redundancy
- Routing Protocol Hierarchy
- Build for IP Forwarding First - then add services

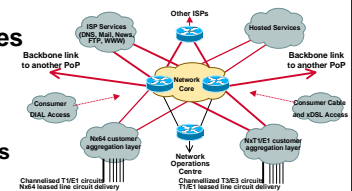
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Modular Design

Organize the Network into separate and repeatable modules

- ✓ Backbone
- ✓ POP
- ✓ Hosting Services
- ✓ ISP Services
- ✓ Support/NOC



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Functional Design

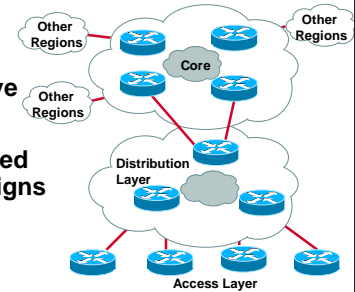
- **One *Box* cannot do everything!** (no matter how hard people have tried in the past)
- Each router/switch in a network has a well-defined set of functions.
- The various *boxes* interact with each other.
- ISP Networks are a systems approach to design.

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Tiered/Hierarchical Network Design

- Flat - Meshed Topologies have not scaled.
- Hierarchy is used in network designs to scale the network.

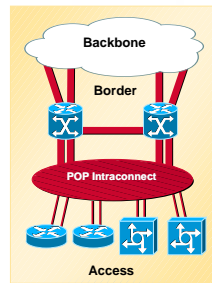


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Multiple Levels of Redundancy

- Triple Layered POP Redundancy
 - ✓ Lower-level failures are better
 - ✓ Lower-level failures may trigger higher-level failures
 - ✓ L2: Two of everything at
 - ✓ L3: IGP and BGP provide redundancy and load balancing
 - ✓ L4: TCP re-transmissions recovers during the fail-over

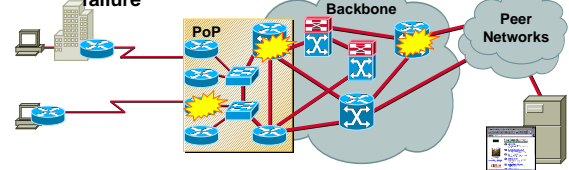


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Multiple Levels of Redundancy

- Objectives -
 - ✓ As little user visibility of a fault as possible
 - ✓ Minimize the impact of any fault in any part of the network.
 - ✓ Network needs to handle L2, L3, L4, and Router failure



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Enterprise Multihoming is Practically a Norm

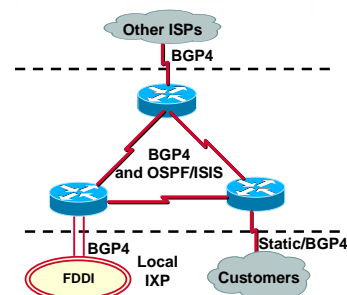
- Many situations possible
 - ✓ multiple sessions to same ISP
 - ✓ secondary for backup only
 - ✓ load-share between primary and secondary
 - ✓ selectively use different ISPs



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Hierarchy of Routing Protocols



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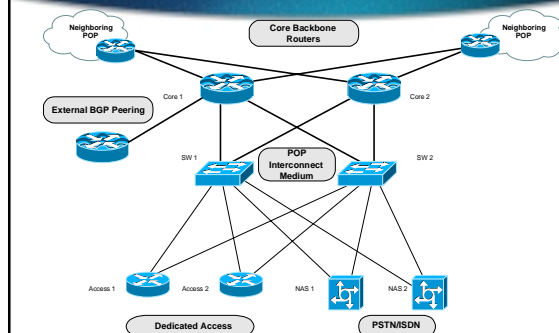
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Point of Presence Topologies

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PoP Design



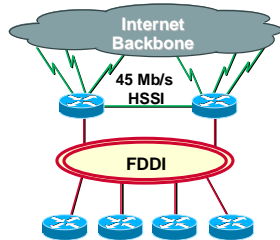
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Early Internet POP Architecture - NSP

- ✓ Backbone trunks at 45 Mb/s
- ✓ Shared media interconnect within POP:
FDDI, Ethernet, Switched Ethernet
- ✓ Conventional T3 backbone Internet router

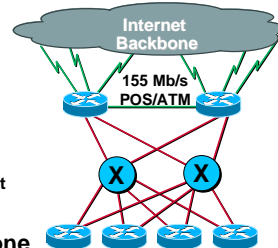


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Internet POP Architecture - '96/'98

- ✓ Backbone trunks at 155 Mb/s
Packet over SONET OC3
ATM OC3
- ✓ Switched interconnect within POP:
Switched FDDI/Fast Ethernet
ATM OC3
- ✓ Advanced OC3 backbone Internet router



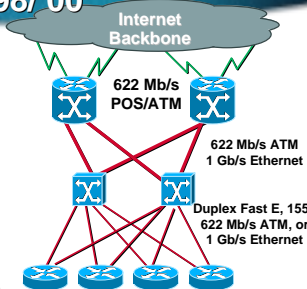
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Internet POP Architecture - '98/'00

- ✓ Backbone trunks at 622 Mb/s
Packet over SONET OC12
ATM OC12
- ✓ Switched interconnect within POP:
ATM at OC3 AND OC12
Ethernet Channel
Gigabit Ethernet (early '98)
POSIP (late '98)
- ✓ Gigabit OC12 backbone Internet router

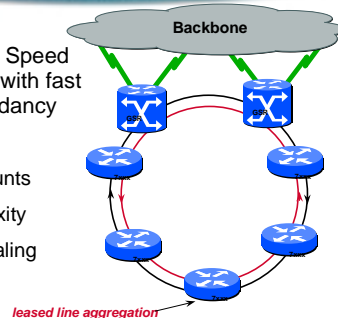


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Internet POP Architecture - '99/'01

- SRP Rings - High Speed of SDH combined with fast failover and redundancy
 - ✓ High bandwidth
 - ✓ Reduced port counts
 - ✓ Reduced complexity
 - ✓ Proactive self healing



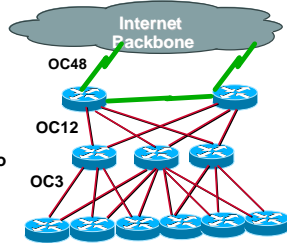
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Large POPs - add a 3rd layer

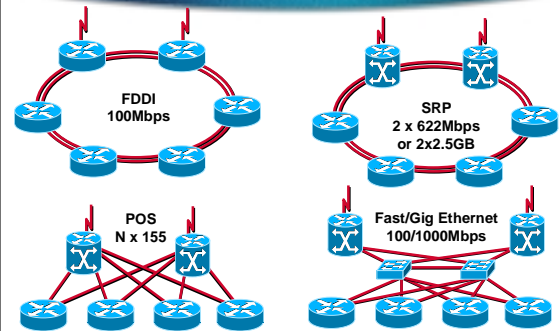
- ✓ Problem: port density!
- ✓ Solution: buy more routers!
- ✓ Customer routers connect to aggregation routers
 - Packet over SONET OC3
 - ATM OC3
- ✓ Aggregation routers connect to backbone routers
- ✓ Scales nicely
- ✓ X CRs to Y ARs to Z BRs
 - ✓ ...where $X > Y > Z$
 - ✓ Be careful not to oversubscribe!



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POP Interconnect Summary



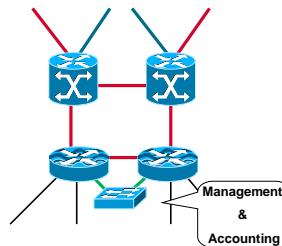
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Key Design Principles

- Interconnection for Management, Security, and Accounting services
 - ✓ Netflow Devices - FlowCollector
 - ✓ Syslog collector for all network devices
 - ✓ SNMP collector (PC Based UNIX)
 - ✓ Security Auditing Tools (NetSonic)

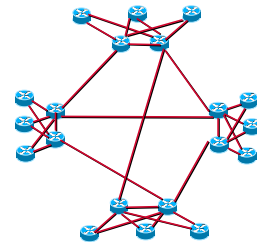


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ISP routing Architectures - IP

- IGP = EIGRP, IS-IS, or OSPF
 - ✓ almost always IS-IS or OSPF
 - ✓ IS-IS, single level (usually L2)
 - ✓ OSPF, either single area or BB/POP areas
- BGP = all routers in full mesh
 - ✓ mesh accomplished with route reflectors, confederations, actual full mesh
- All routers have all routes, so services could go anywhere



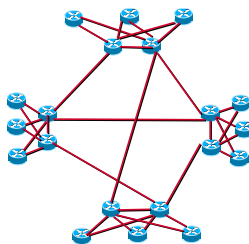
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ISP routing Architectures - IP+MPLS

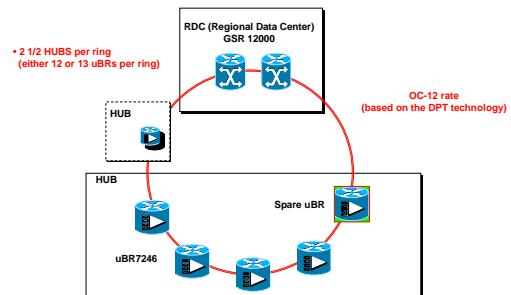
- IGP = EIGRP, IS-IS, or OSPF
 - ✓ must be IS-IS or OSPF to use MPLS TE
- BGP = only edge routers need full routes
 - ✓ full-mesh of edge routers using aforementioned mechanisms
 - ✓ packets are forwarded via LDP labels, not IP destination address
- Where to put your services?
 - ✓ cannot hang a cache service off of a router that doesn't have full routes!



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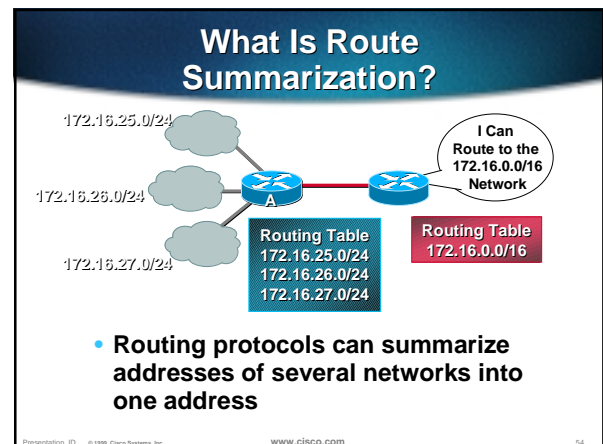
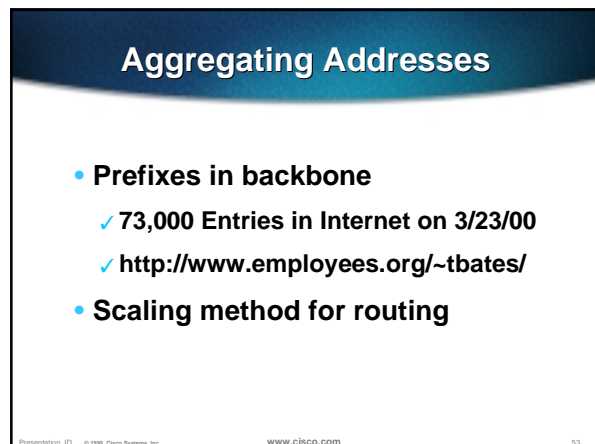
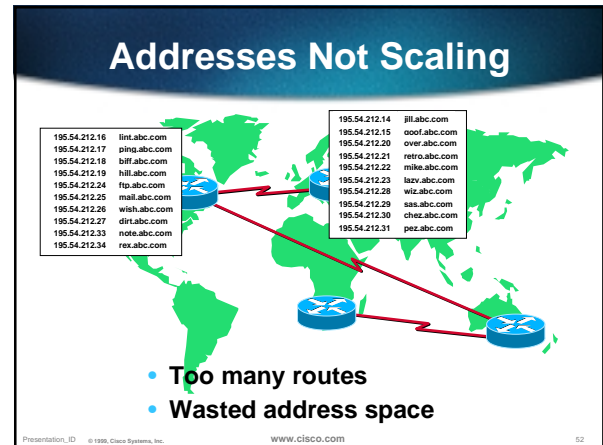
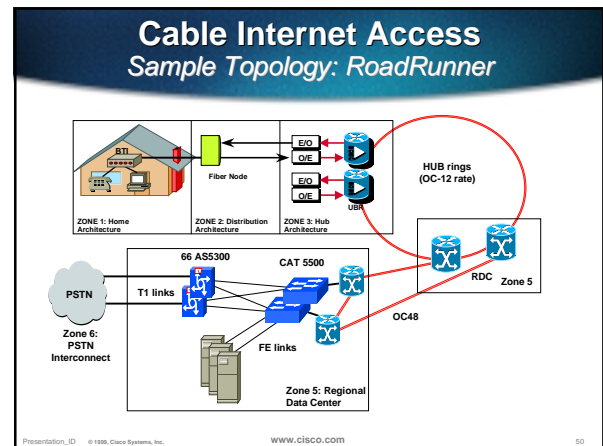
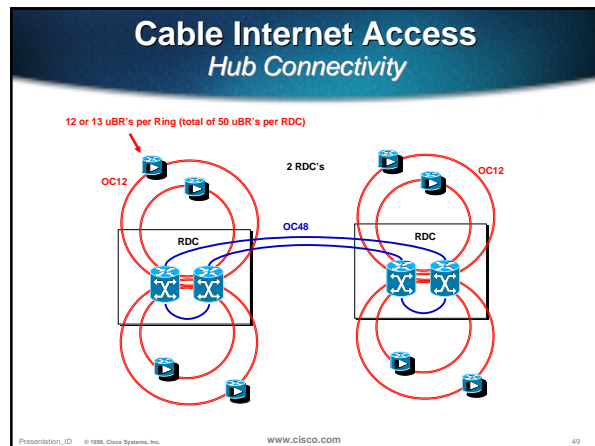
Cable Internet Access Hub Connectivity



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Route Aggregation

Old Method:

202.14.64.0
202.14.65.0
202.14.66.0
⋮
202.14.96.0

→ 32 Routes

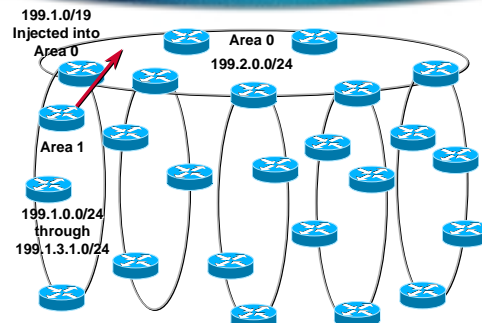
New Method:

202.14.64.0/19 → 1 Route

- 131.108.0.0 /16 versus 255.255.0.0
- Summarizable blocks of subnets

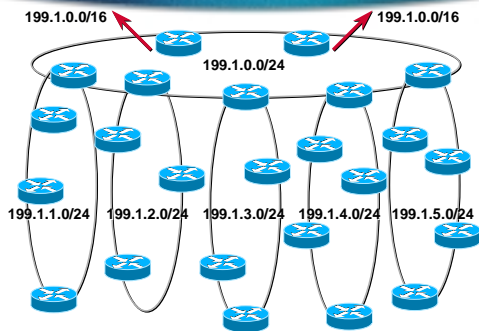
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Intra-Domain Route Summarization



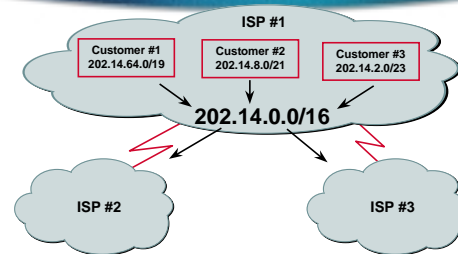
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Inter-Domain Route Summarization



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Addressing and ISPs

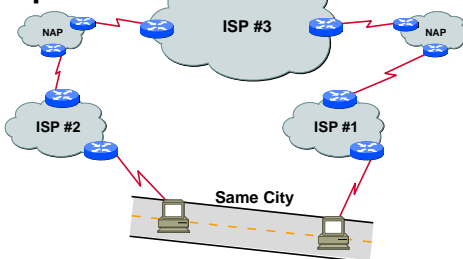


- Smaller routes aggregated within ISP #1

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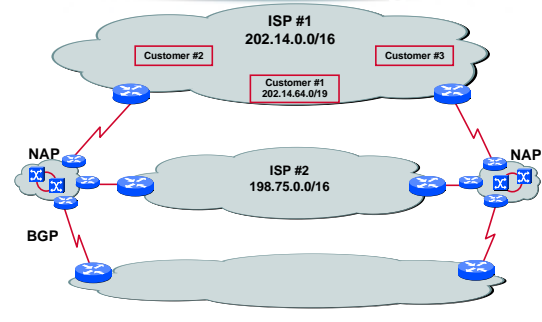
Border Gateways

- How it affects your traffic patterns



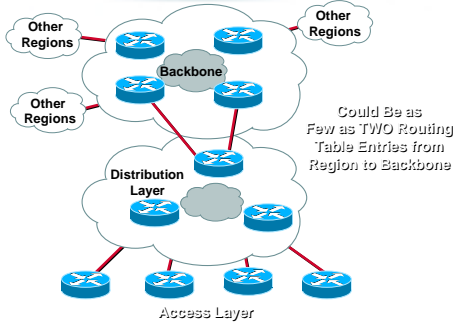
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Scaling the Internet: Addressing



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Minimum Routing Table Entries



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Separate Infrastructure and Customer Addressing

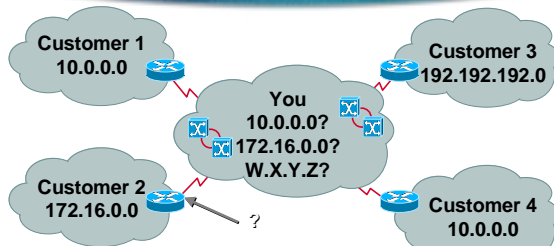
- Eases administration of policies
- Security and management
- Routing management
- Don't share network 10!

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Customer vs. Infrastructure



See Session #1306 "Expanding Connectivity With NAT"

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Classless Routing Protocols

- Supports Variable Length Subnet Masks (VLSM's) and non-contiguous subnetting
- OSPF, integrated IS-IS, EIGRP, RIPv2 and BGP
- Classful routing protocols are effectively deprecated

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Default Config for All Routers

- All routers should have the following configuration commands for full CIDR routing:
 - ✓ ip classless
 - ✓ ip subnet-zero
 - ✓ router bgp XXXX
 - ✓ no auto-summary

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Adding Services to the Architecture

Cause and Effect

1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021 2023 2025 2027 2029 2031 2033 2035 2037 2039 2041 2043 2045 2047 2049 2051 2053 2055 2057 2059 2061 2063 2065 2067 2069 2071 2073 2075 2077 2079 2081 2083 2085 2087 2089 2091 2093 2095 2097 2099 2101 2103 2105 2107 2109 2111 2113 2115 2117 2119 2121 2123 2125 2127 2129 2131 2133 2135 2137 2139 2141 2143 2145 2147 2149 2151 2153 2155 2157 2159 2161 2163 2165 2167 2169 2171 2173 2175 2177 2179 2181 2183 2185 2187 2189 2191 2193 2195 2197 2199 2201 2203 2205 2207 2209 2211 2213 2215 2217 2219 2221 2223 2225 2227 2229 2231 2233 2235 2237 2239 2241 2243 2245 2247 2249 2251 2253 2255 2257 2259 2261 2263 2265 2267 2269 2271 2273 2275 2277 2279 2281 2283 2285 2287 2289 2291 2293 2295 2297 2299 2301 2303 2305 2307 2309 2311 2313 2315 2317 2319 2321 2323 2325 2327 2329 2331 2333 2335 2337 2339 2341 2343 2345 2347 2349 2351 2353 2355 2357 2359 2361 2363 2365 2367 2369 2371 2373 2375 2377 2379 2381 2383 2385 2387 2389 2391 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Services? How many Services?

Most network services are applied at the edge!

Edge (one-time) services

- Voice over IP
- MPLS VPNs
- CDNs
- VPDNs
- Managed services
- Dial—DSL—cable

Per-hop services

- MPLS packet forwarding
- DiffServ, other QoS
- Multicast Services

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Ask the Right Questions

- What is the value of the service?
 - ✓ Technical merit
 - ✓ Cost savings
 - ✓ Marketecture
- What is the cost of the service?
 - ✓ Equipment?
 - ✓ Training people to support it?
 - ✓ Network buildouts/topology changes?

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Impact of Services on the Network

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Who Knows?

- What will be the impact on existing traffic loads/patterns?
- Can the network deliver the performance that your customers/applications desire? delay? jitter (delay variation)?
- Make sure to add capacity as you add services - bandwidth is a must.

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Deployment of New Services

- Is more of a business decision
- The technical aspect is to ensure continued network performance—scalability and stability
- Try to keep services within your AS
 - ✓ end2end control
 - ✓ less likelihood of failure/flaps

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Deploying New Services

- Don't feed the hype fire
- Look *before* you leap!
- Don't deploy new technologies and services just for the sake of it; have valid business and technical reasons

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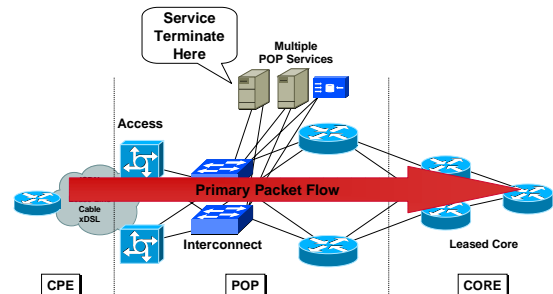
Deploying New Services

- Usually a Service requires a TCP/UDP termination (I.e. TCP's three way handshake)
- Termination should happen out side of the *primary flow path*
- Otherwise, the network is then designed around the single service.

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Deploying New Services



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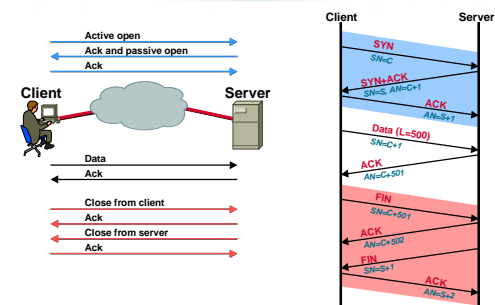
TCP/UDP Termination in The POP

Factors Effecting any product design

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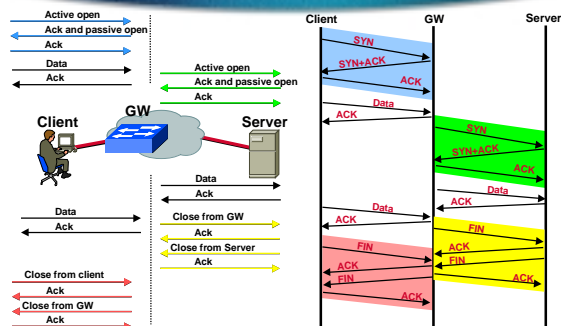
Connections Establishment and Termination



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Termination with GW or L7 Switch

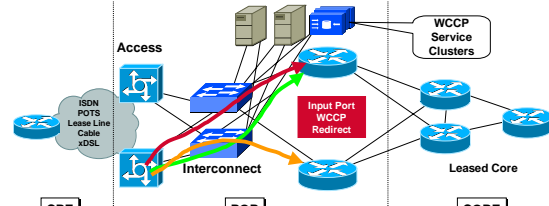


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Equal Path Load Balancing through the POP

- Work with the multi-level L2/L3 redundancy of the ISP POP. Equal paths in the IGP + CEF leads packet asymmetry.



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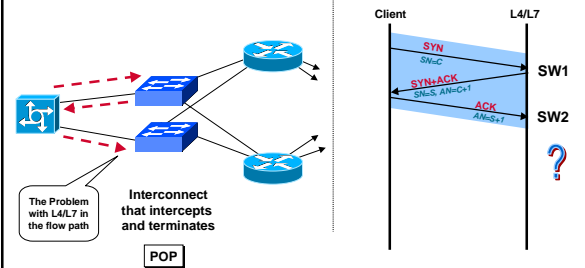
The Major Problem

- **Cannot assume that the NAS boxes will comply to a L4/L7 switches requirements of forced symmetry**
 - ✓ Per packet round robin - default for most NAS gear. Most Cisco NAS boxes left in this mode (no CEF).
 - ✓ Per destination - If full routes - OK. Equal cost defaults in the POP, then back to per packet.
 - ✓ Hash of source/destination. Only mode that will work for L4/L7 switches.

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How the Packets Flow through the POP

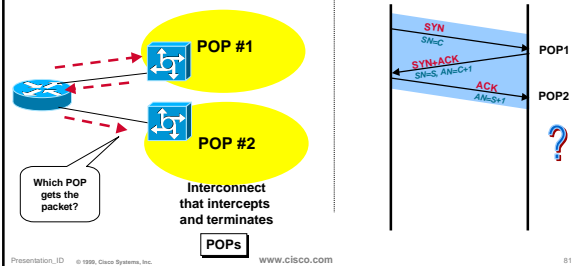
Worse Case Scenario - Per Packet Load Balancing with four equal cost paths to default routes on the POP GW



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How the Packets Flow through the POP

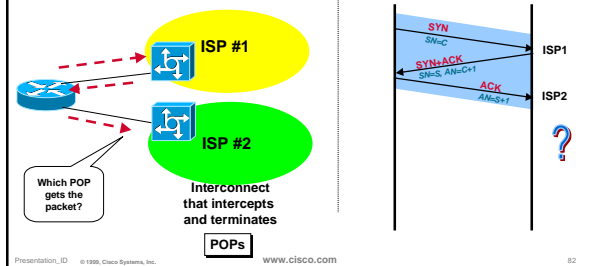
An Even Worse Case - Per Packet Load Balancing from an multihomed enterprise with two equal cost paths to the same ISP



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How the Packets Flow through the POP

Absolute Worse Case - Per Packet Load Balancing from an multihomed enterprise with two equal cost paths to the two or more ISPs



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Make No Assumptions!

- **Cascading switching paths**
 - ✓ Optimum -> fast switching -> process switching
 - ✓ CEF replaces optimum switching
 - ✓ CEF -> fast switching -> process switching
 - ✓ DCEF -> CEF -> fast switching -> process switching
- All of this effects the equal cost load balancing technique.
- Certain features drop out of CEF into fast or process switching

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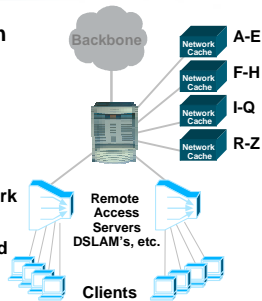
What to do?

- **Cannot trust the equal cost load balancing to keep the traffic flow symmetrical.**
- **That leaves two solutions:**
 - ✓ Force symmetry with one POP interconnect device
 - ✓ Separate the identification and redirection functions of transparent interception from the termination function.

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Force Symmetry in the POP

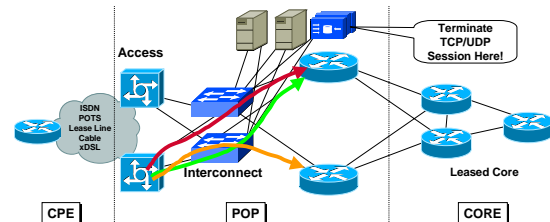
- Use only one L4/L7 switch in the POP
 - ✓ No POP interconnect redundancy
 - ✓ Only Ethernet Topologies - no SRP/DRP or ATM solutions
 - ✓ No five "9s" end-to-end network reliability
 - ✓ Will not work with multi-homed customers



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Separate the Transparent Interception Functions

Do a L3/L4 redirect first - then terminate! This works with multi-level L2/L3 redundancy and packet asymmetry in the ISP POP - but not multi-homed customers.



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Web Cache Communication Protocol (WCCP)

- Content Routing Technology first introduced in 1997
- Provides mechanism to redirect traffic flows [originally caches] in real-time
- Has in-built load-balancing mechanism, scaling, fault tolerance, and service-assurance (failsafe) mechanisms

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Web Cache Communication Protocol (WCCP)

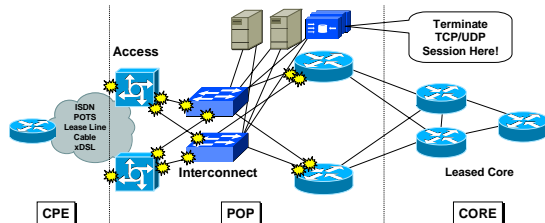
- WCCPv1/WCCPv2 implemented by several vendors:
 - ✓ Inktomi, NetApps, CacheFlow, Novell, Infolibra - original licensees
 - ✓ Squid has a version with WCCPv1 w/ WCCPv2 coming (when Lincoln has time)



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Separate the Transparent Interception Functions

- Provide the ISP with Flexibility on the point of redirection. Do not force an architecture on the customer.



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Mindfulness

Things that will make or break your business.

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Managing the Network

- Documentation (for real)
- Plan ahead
- Know your limits and the limits of your network
- Traffic Engineering 101
- Service Contract - PICA

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Scaling Operations

- Few operators allowed to configure backbone infrastructure
- Define clear processes/automate customer provisioning
- Documentation, simplicity, and repetition

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Empowering People

- **People**—not bandwidth, content, or applications—are THE most critical factor
- Raise skills
- Provide Tools



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Labs and Testing

- Cisco IOS™ is the OS for your Network
- Test new releases with existing applications, like a new server OS release
- Test new applications on a test network before deployment, like a test server
- An ounce of preparation is worth...

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Addendum - Equal Cost Forwarding

How IP Forwarding works with equal cost paths

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Equal Cost Forwarding

- Router discovers multiple paths to a destination via a routing protocol.
- The forward table is updated with multiple entries to that destination:

```
router> show ip route
[...]
```

I	192.168.25.0/24	[115/10]	via 192.168.24.6
			[115/10] via 192.168.24.10
			[115/10] via 192.168.24.14

```
[...]
```

- If metric are equal, the router will forward the packets using one of several load balancing techniques

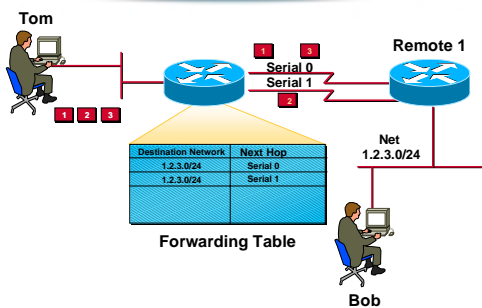
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Types of Equal Cost Forwarding

- Per packet round robin
- Per destination
- Hash of source/destination

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Per Packet Round Robin



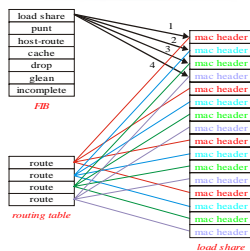
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Per Packet Load Balancing

- Supported on all routers.
- Processor intensive - CPU hit.
- Prone to out of order packets in some situations.
- CEF has per-packet load balancing - but with out the CPU hit on the processor.

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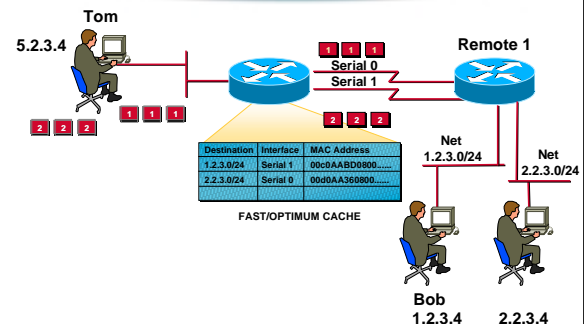
CEF's Per Packet Load Balancing



Round robin between 16 buckets.

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Per-Destination



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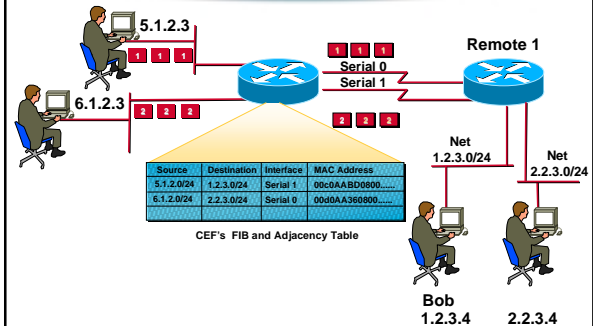
Per Destination Load Balancing

- Based on the *cached* destination
- Supported on cached based switching - fast switching, optimum switching, and optimum/flow switching
- Eliminated the out of order packet issues, but creates the issue of traffic polarization.

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Hashed Source/Destination



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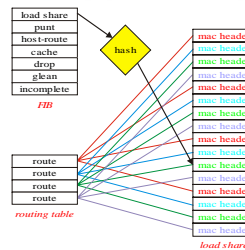
Hashed Source/Destination

- Based on a hash of the source and destination addresses.
- This insures that each source/destination pair will be sent out the same interface.
- In some cases, it will have traffic polarization issues (fix coming for CEF).

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CEF'S Hashed Source/Destination



By default, then, traffic is load balanced based on both the source and destination address; each packet sourced from a given host and destined to a given network will always choose the same next hop.

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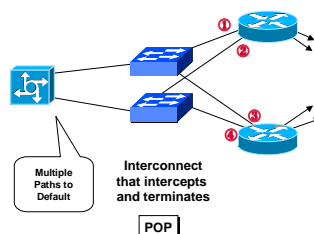
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How many Paths?

IGP in the POP with POP GWs Originating Default to the POP Devices w/ flat ethernet.

Four paths with each over each link
8 equal paths to default



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