ISP & IXP Design

Philip Smith

APNIC 34

21st – 31st August 2012

ISP & IXP Network Design

- PoP Topologies and Design
- Backbone Design
- Upstream Connectivity & Peering
- Addressing
- Routing Protocols
- Out of Band Management
- Operational Considerations
- Internet Exchange Points

Point of Presence Topologies

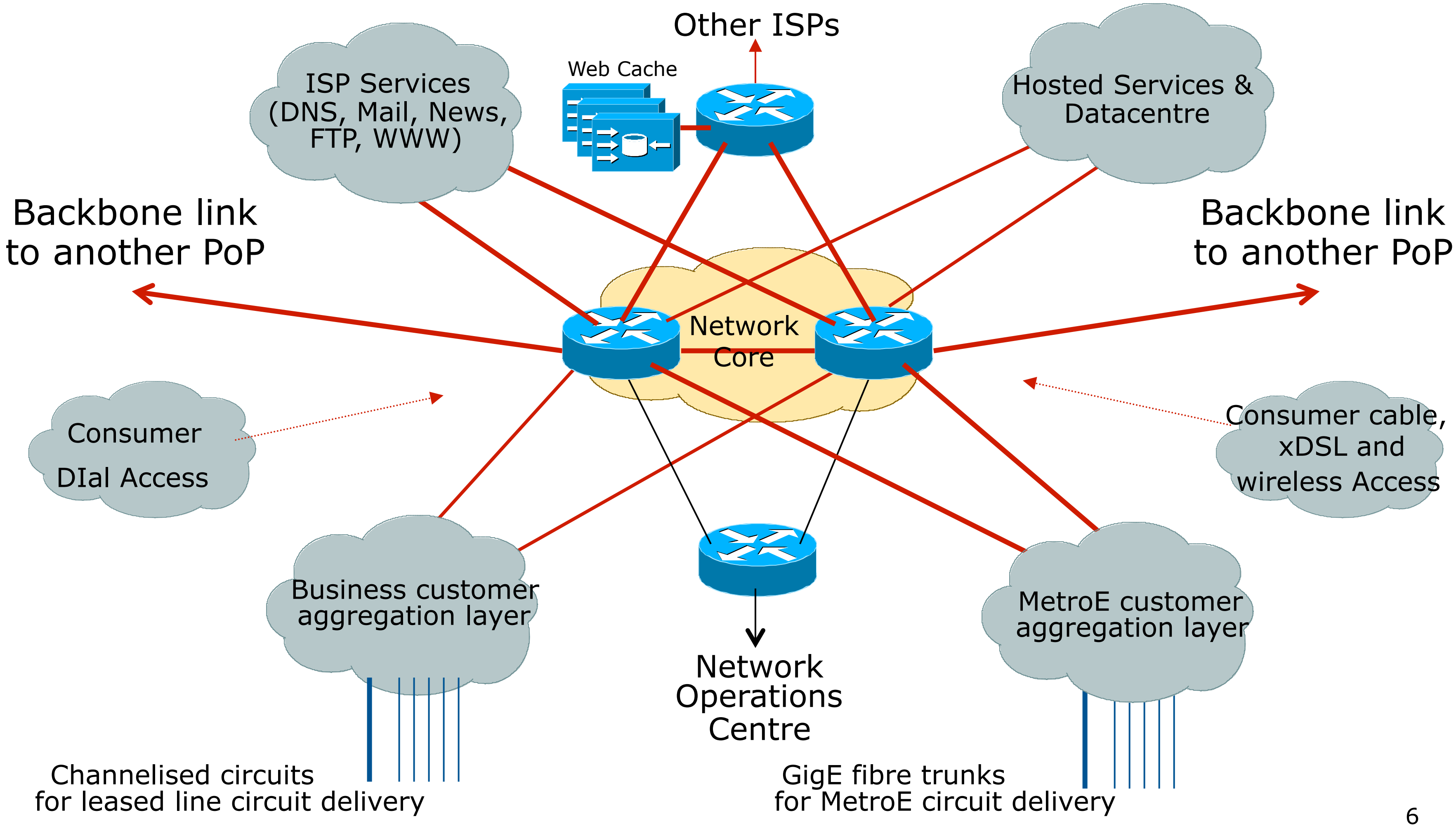
PoP Topologies

- Core routers – high speed trunk connections
- Distribution routers and Access routers – high port density
- Border routers – connections to other providers
- Service routers – hosting and servers
- Some functions might be handled by a single router

PoP Design

- Modular Design
- Aggregation Services separated according to
  - connection speed
  - customer service
  - contention ratio
  - security considerations

Modular PoP Design



Modular Routing Protocol Design

- Modular IGP implementation
  - IGP “area” per PoP
  - Core routers in backbone area (Area 0/L2)
  - Aggregation/summarisation where possible into the core
- Modular iBGP implementation
  - BGP route reflector cluster
  - **Core routers** are the route-reflectors
  - Remaining routers are clients & peer with route-reflectors only

Point of Presence Design

PoP Modules

- Low Speed customer connections
  - PSTN/ISDN dialup
  - Low bandwidth needs
  - Low revenue, large numbers
- Leased line customer connections
  - E1/T1 speed range
  - Delivery over channelised media
  - Medium bandwidth needs
  - Medium revenue, medium numbers

PoP Modules

- Broad Band customer connections
  - xDSL, Cable and Wireless
  - High bandwidth needs
  - Low revenue, large numbers
- MetroE & Highband customer connections
  - Trunk onto GigE or 10GigE of 10Mbps and higher
  - Channelised OC3/12 delivery of E3/T3 and higher
  - High bandwidth needs
  - High revenue, low numbers

PoP Modules

- PoP Core
  - Two dedicated routers
  - High Speed interconnect
  - Backbone Links ONLY
  - *Do not touch them!*
- Border Network
  - Dedicated border router to other ISPs
  - The ISP's "front" door
  - Transparent web caching?
  - Two in backbone is minimum guarantee for redundancy

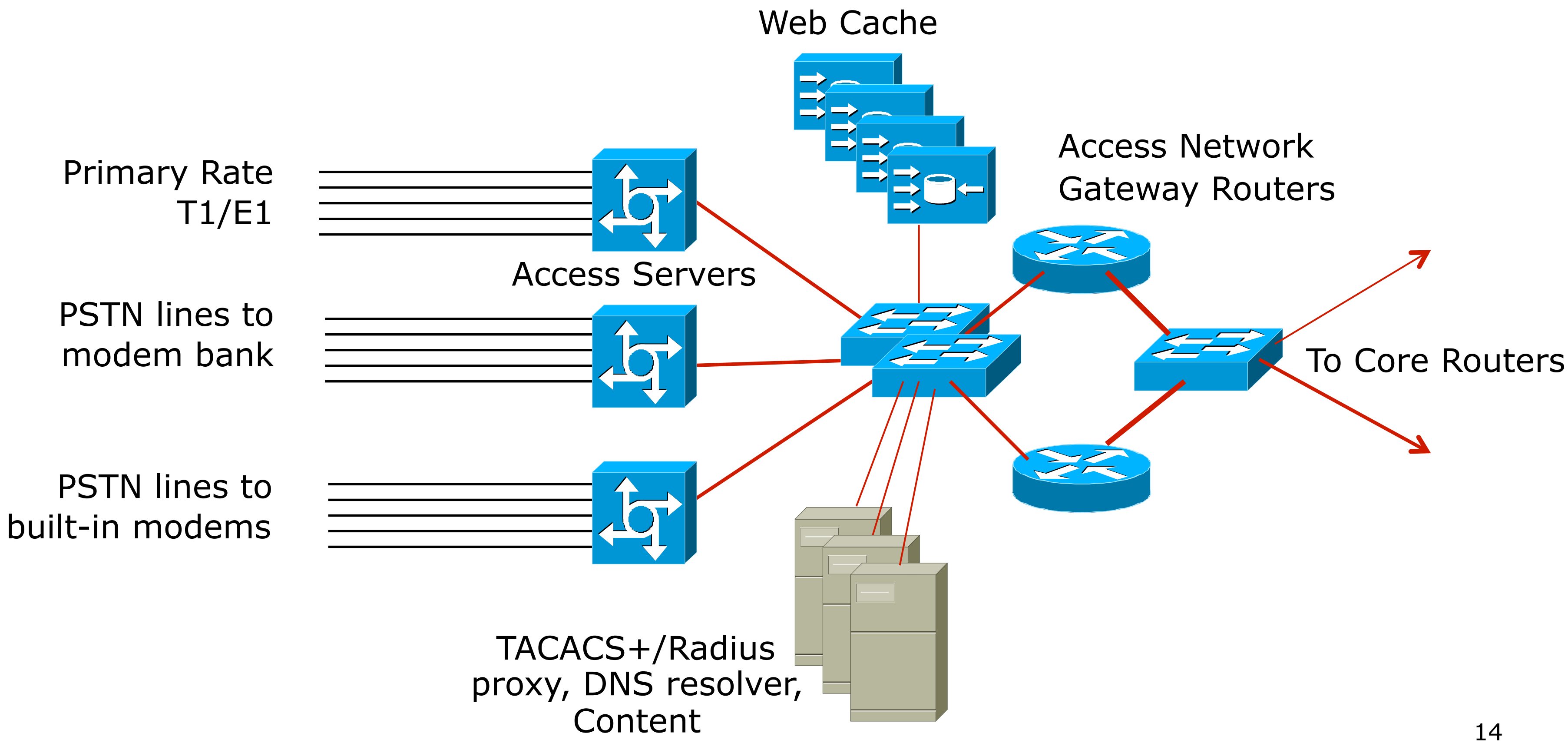
PoP Modules

- ISP Services
  - DNS (cache, secondary)
  - News (still relevant?)
  - Mail (POP3, Relay, Anti-virus/anti-spam)
  - WWW (server, proxy, cache)
- Hosted Services/DataCentres
  - Virtual Web, WWW (server, proxy, cache)
  - Information/Content Services
  - Electronic Commerce

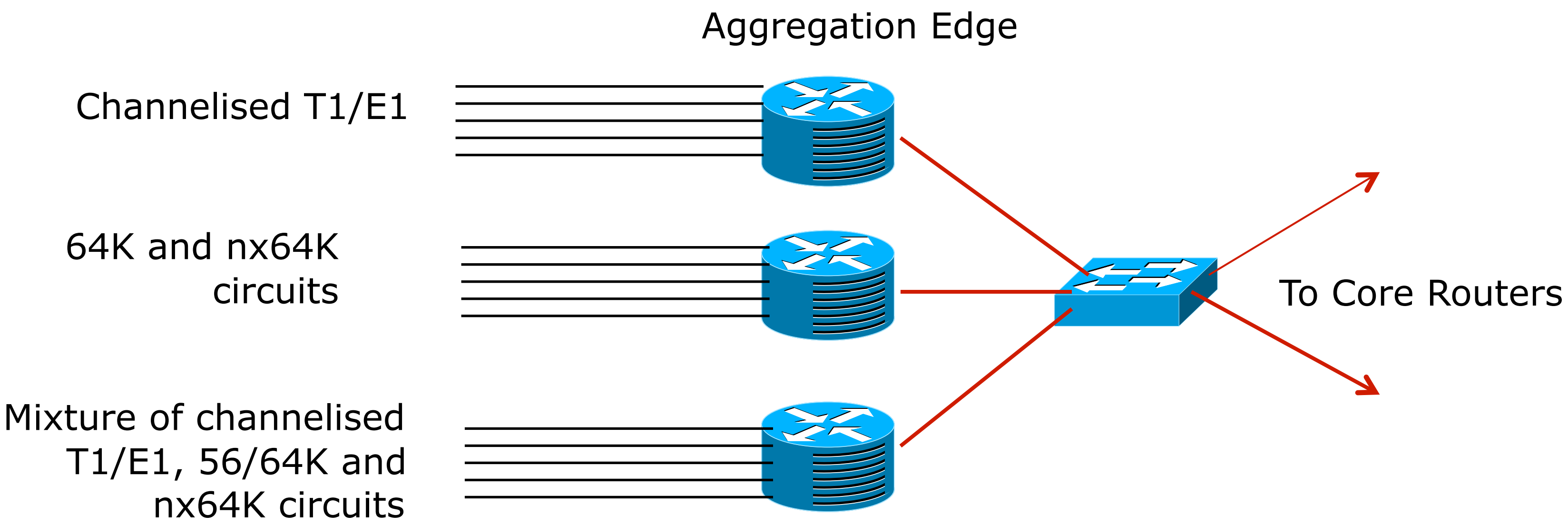
PoP Modules

- Network Operations Centre
  - Consider primary and backup locations
  - Network monitoring
  - Statistics and log gathering
  - Direct but secure access
- Out of Band Management Network
  - The ISP Network "Safety Belt"

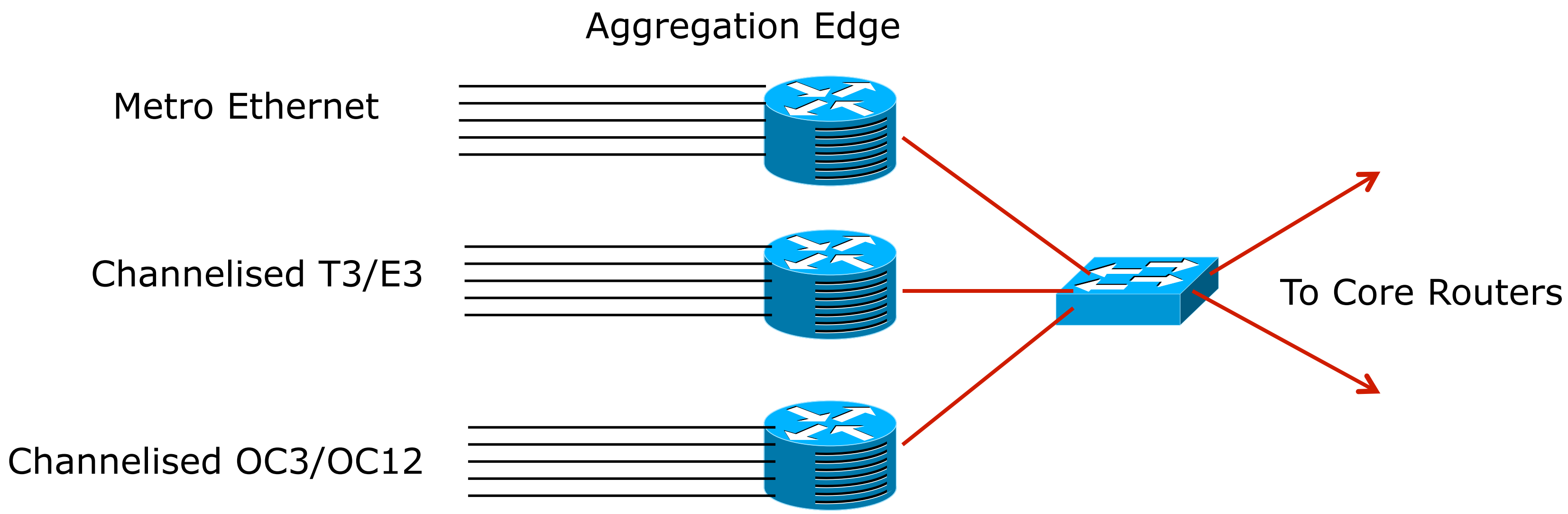
Low Speed Access Module



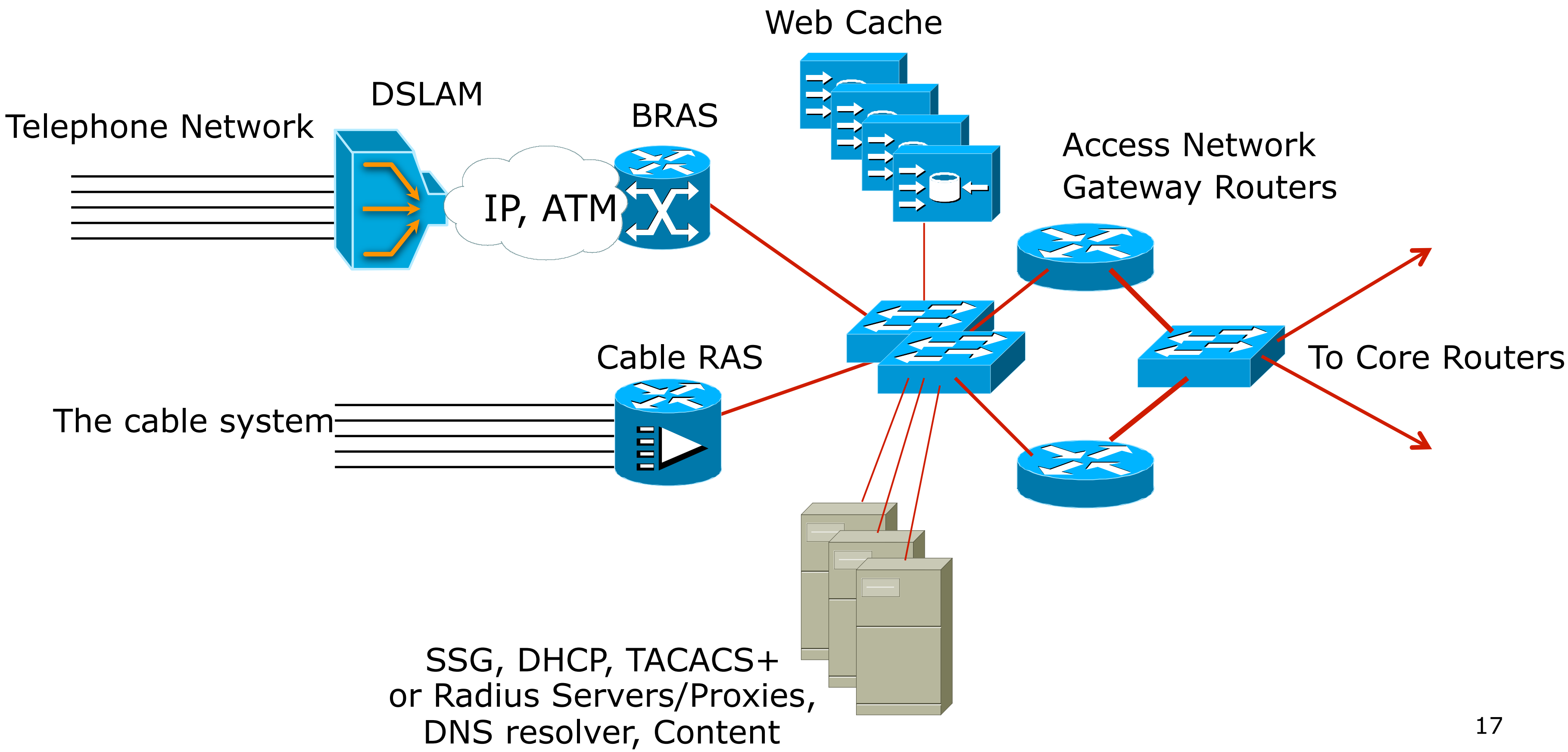
Medium Speed Access Module



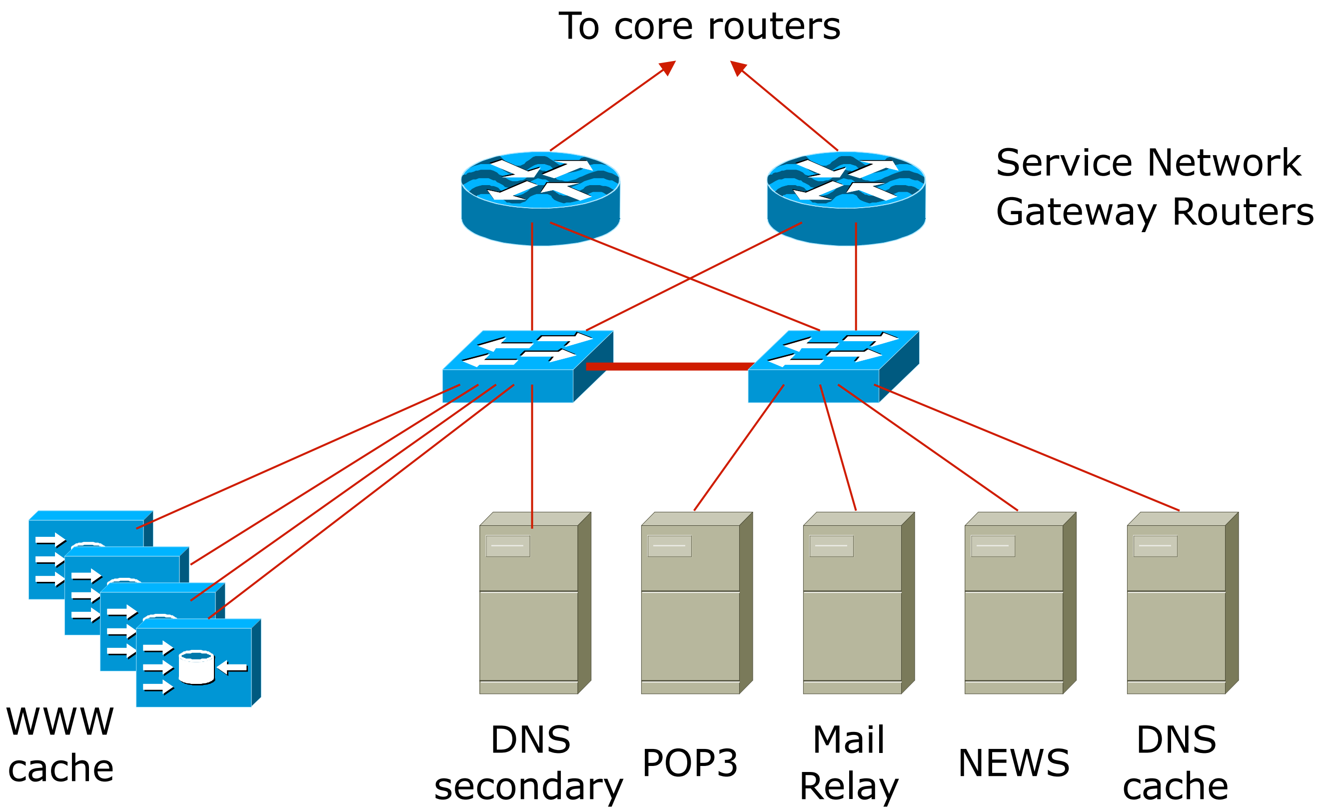
High Speed Access Module



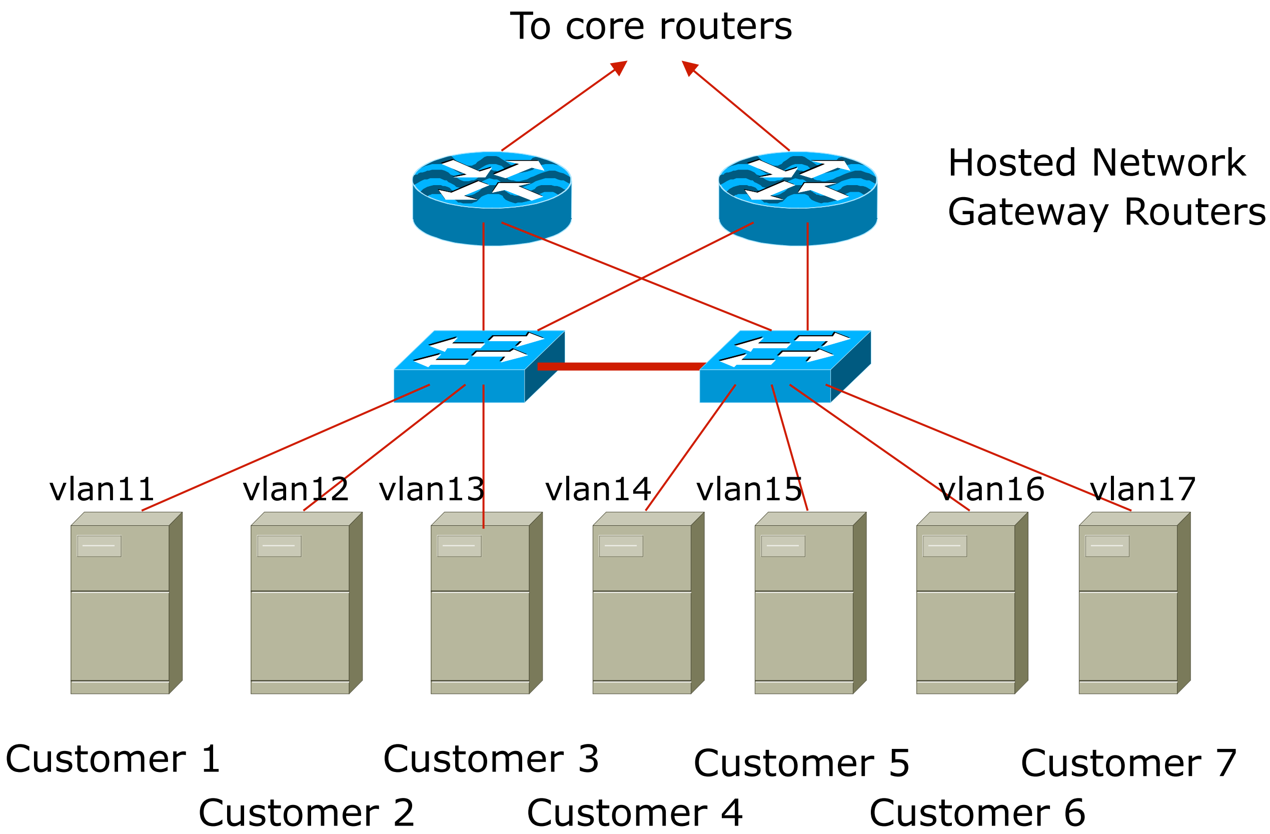
Broadband Access Module



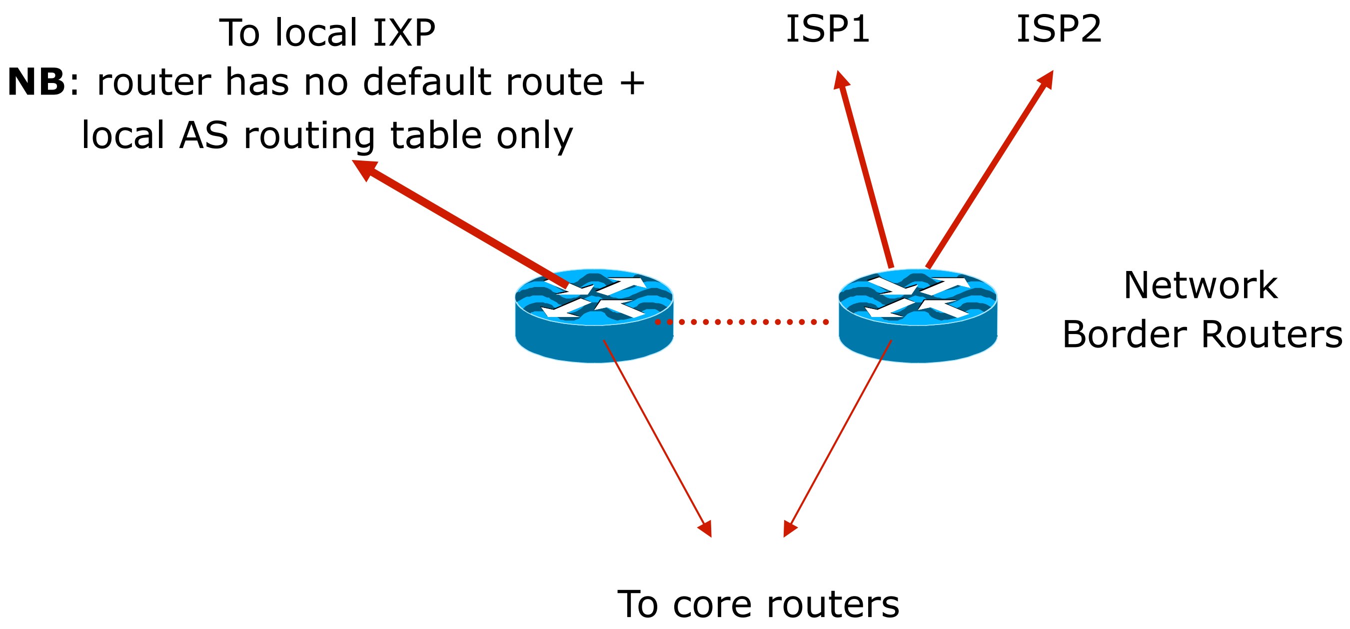
ISP Services Module



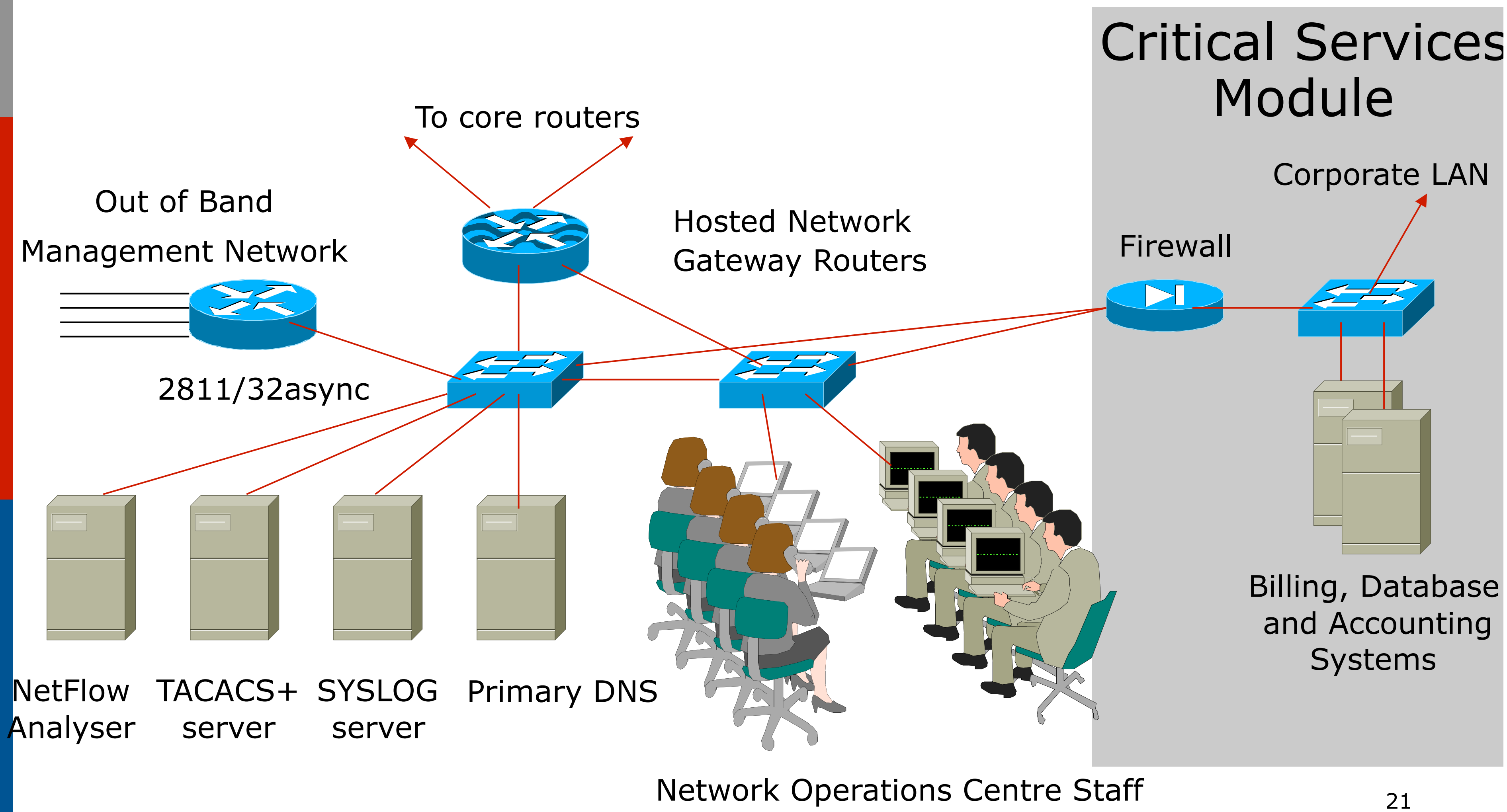
Hosted Services Module



Border Module

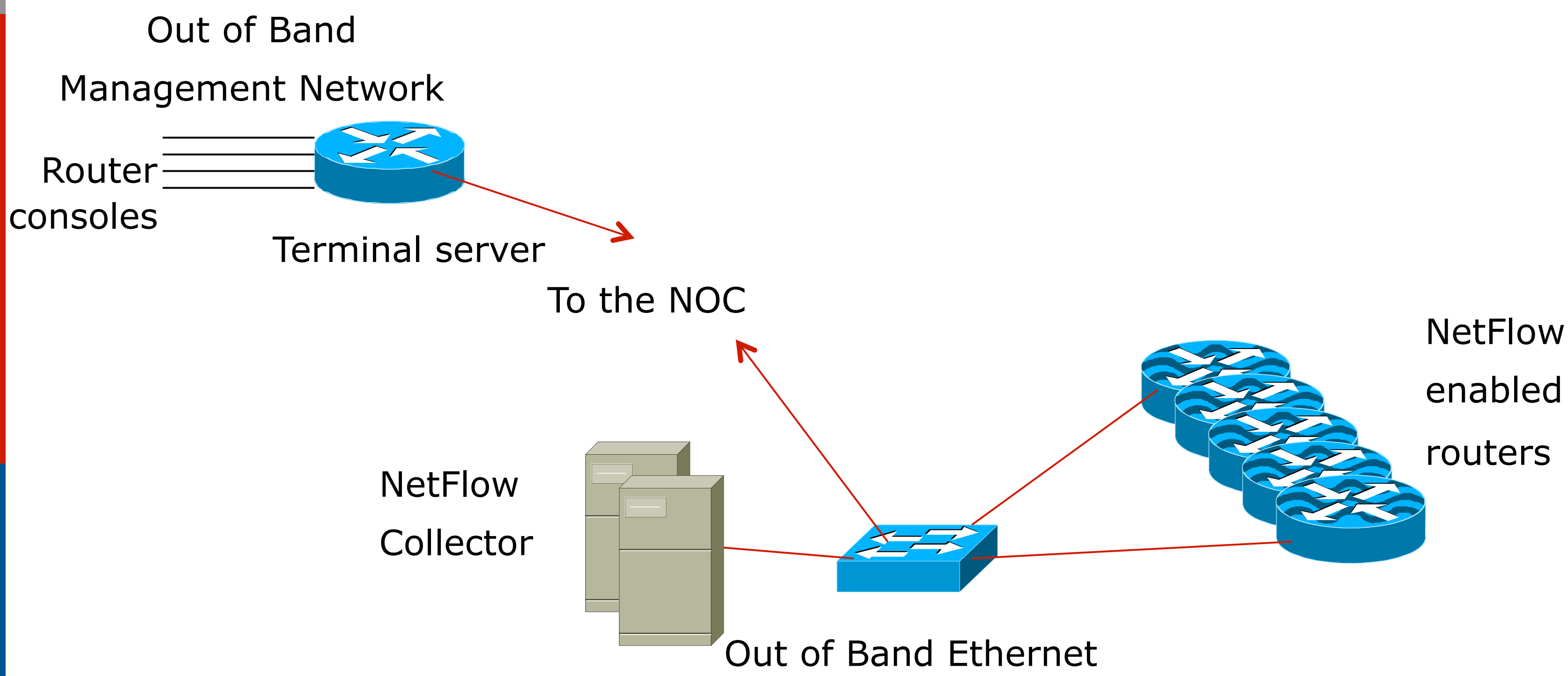


NOC Module



Critical Services Module
To core routers
Out of Band
Management Network
Hosted Network
Gateway Routers
Corporate LAN
Firewall
2811/32async
Billing, Database and Accounting Systems
NetFlow Analyser
TACACS+ server
SYSLOG server
Primary DNS
Network Operations Centre Staff

Out of Band Network



Backbone Network Design

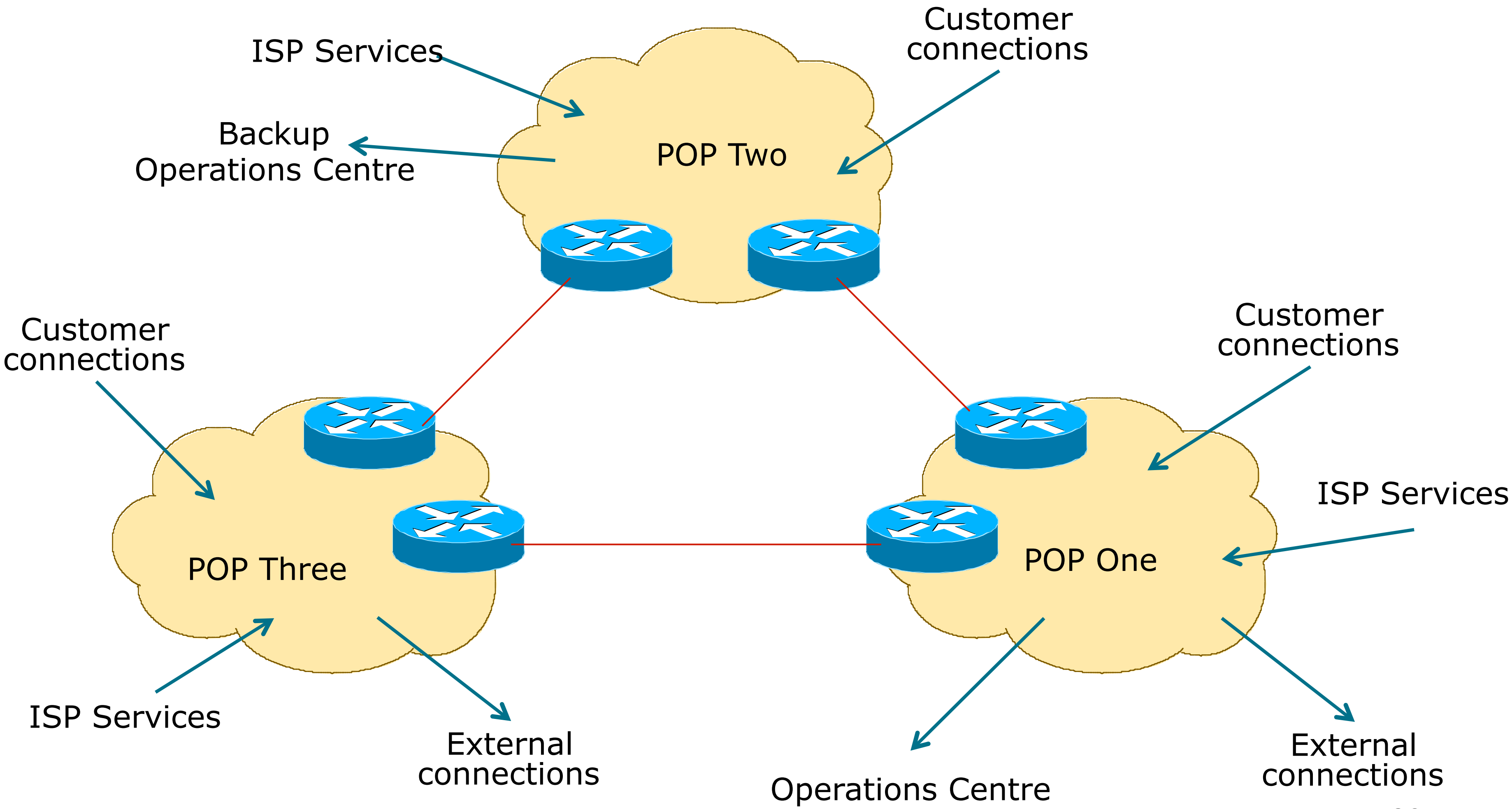
Backbone Design

- Routed Backbone
- Switched Backbone
  - Virtually obsolete
- Point-to-point circuits
  - nx64K, T1/E1, T3/E3, OC3, OC12, GigE, OC48, 10GigE, OC192, OC768
- ATM/Frame Relay service from telco
  - T3, OC3, OC12,… delivery
  - Easily upgradeable bandwidth (CIR)
  - Almost vanished in availability now

Distributed Network Design

- PoP design “standardised”
  - operational scalability and simplicity
- ISP essential services distributed around backbone
- NOC and “backup” NOC
- Redundant backbone links

Distributed Network Design



Backbone Links

- ATM/Frame Relay
  - Virtually disappeared due to overhead, extra equipment, and shared with other customers of the telco
  - MPLS has replaced ATM & FR as the telco favourite
- Leased Line/Circuit
  - Most popular with backbone providers
  - IP over Optics and Metro Ethernet very common in many parts of the world

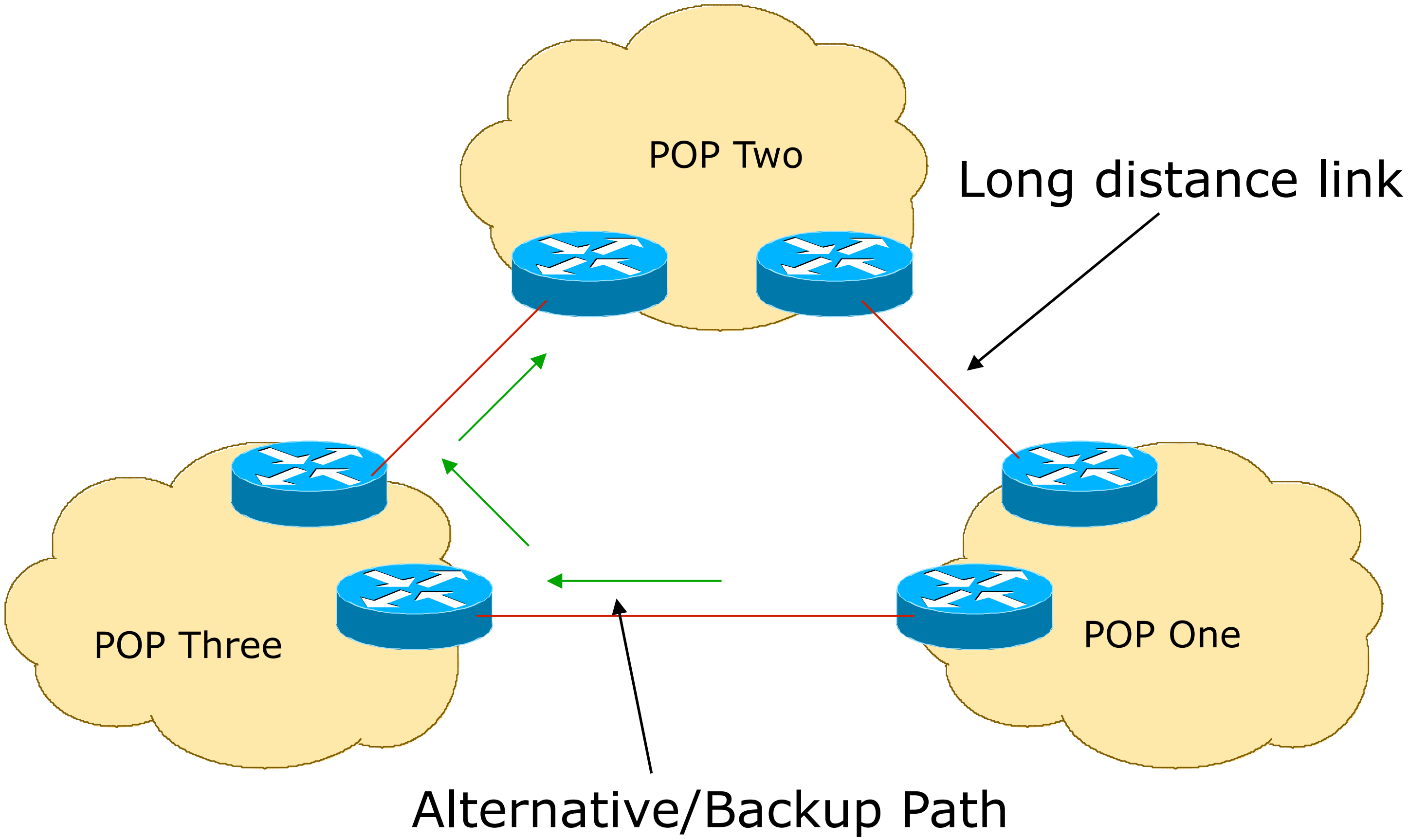
Long Distance Backbone Links

- These usually cost more
- Important to plan for the future
  - This means at least two years ahead
  - Stay in budget, stay realistic
  - Unplanned "emergency" upgrades will be disruptive without redundancy in the network infrastructure

Long Distance Backbone Links

- Allow sufficient capacity on alternative paths for failure situations
  - Sufficient can depend on the business strategy
  - Sufficient can be as little as 20%
  - Sufficient is usually over 50% as this offers “business continuity” for customers in the case of link failure
  - Some businesses choose 0%
    - Very short sighted, meaning they have no spare capacity at all!!

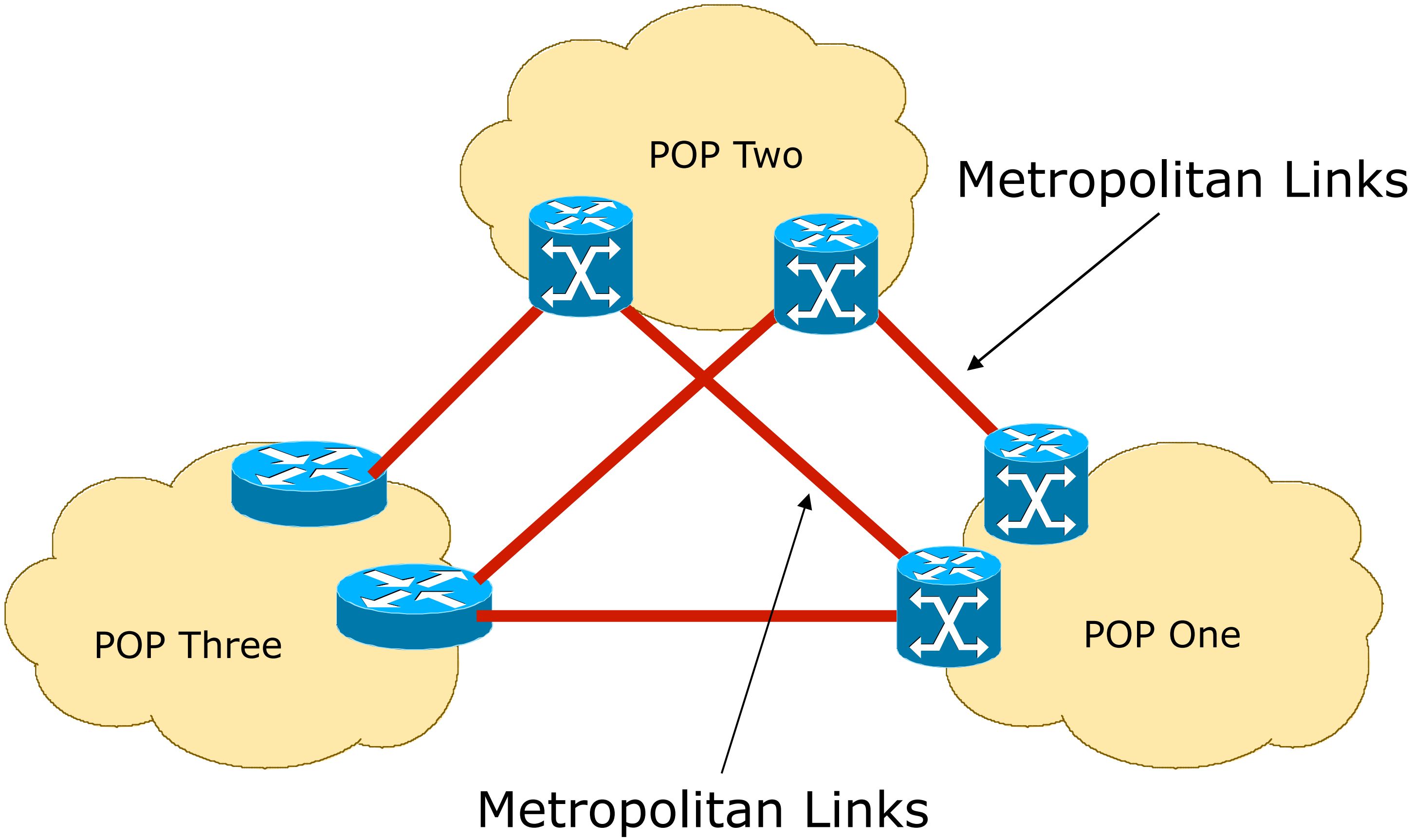
Long Distance Links



Metropolitan Area Backbone Links

- Tend to be cheaper
  - Circuit concentration
  - Choose from multiple suppliers
- Think big
  - More redundancy
  - Less impact of upgrades
  - Less impact of failures

Metropolitan Area Backbone Links



Traditional Point to Point Links

Upstream Connectivity and Peering

Transits

- Transit provider is another autonomous system which is used to provide the local network with access to other networks
  - Might be local or regional only
  - But more usually the whole Internet
- Transit providers need to be chosen wisely:
  - Only one
    - no redundancy
  - Too many
    - more difficult to load balance
    - no economy of scale (costs more per Mbps)
    - hard to provide service quality
- **Recommendation: at least two, no more than three**

Common Mistakes

- ISPs sign up with too many transit providers
  - Lots of small circuits (cost more per Mbps than larger ones)
  - Transit rates per Mbps reduce with increasing transit bandwidth purchased
  - Hard to implement reliable traffic engineering that doesn't need daily fine tuning depending on customer activities
- No diversity
  - Chosen transit providers all reached over same satellite or same submarine cable
  - Chosen transit providers have poor onward transit and peering

Peers

- A peer is another autonomous system with which the local network has agreed to exchange locally sourced routes and traffic
- Private peer
  - Private link between two providers for the purpose of interconnecting
- Public peer
  - Internet Exchange Point, where providers meet and freely decide who they will interconnect with
- **Recommendation: peer as much as possible!**

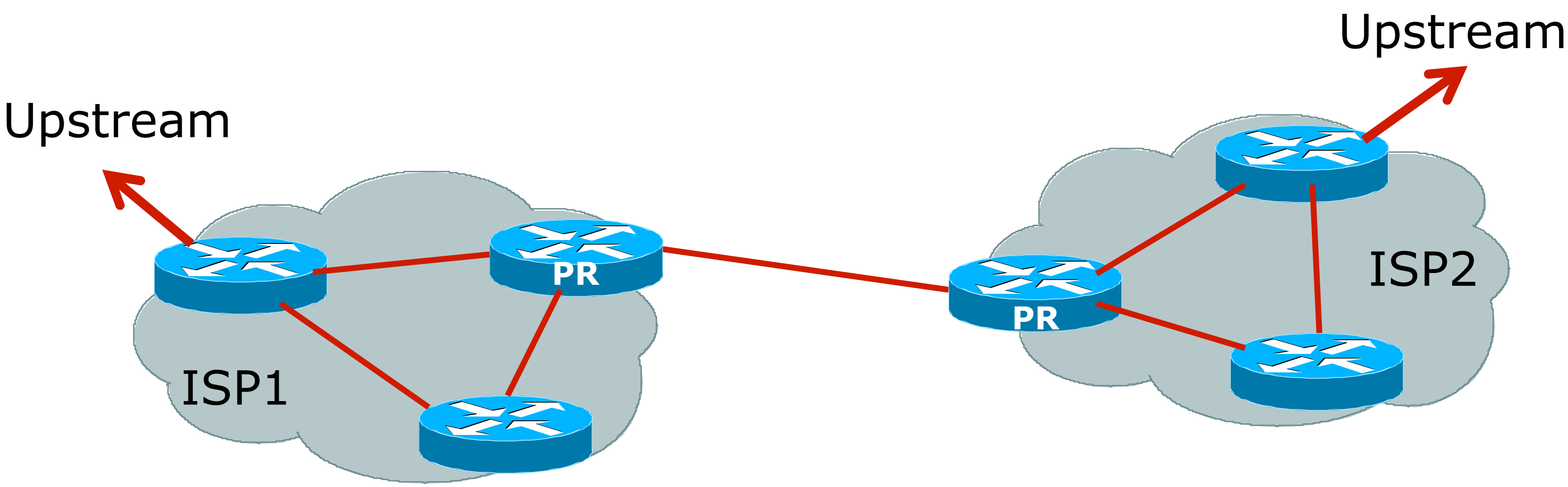
Common Mistakes

- Mistaking a transit provider's "Exchange" business for a no-cost public peering point
- Not working hard to get as much peering as possible
  - Physically near a peering point (IXP) but not present at it
  - (Transit is rarely cheaper than peering!!)
- Ignoring/avoiding competitors because they are competition
  - Even though potentially valuable peering partner to give customers a better experience

Private Interconnection

- Two service providers agree to interconnect their networks
  - They exchange prefixes they originate into the routing system (usually their aggregated address blocks)
  - They share the cost of the infrastructure to interconnect
    - Typically each paying half the cost of the link (be it circuit, satellite, microwave, fibre,…)
    - Connected to their respective peering routers
  - Peering routers only carry domestic prefixes

Private Interconnection

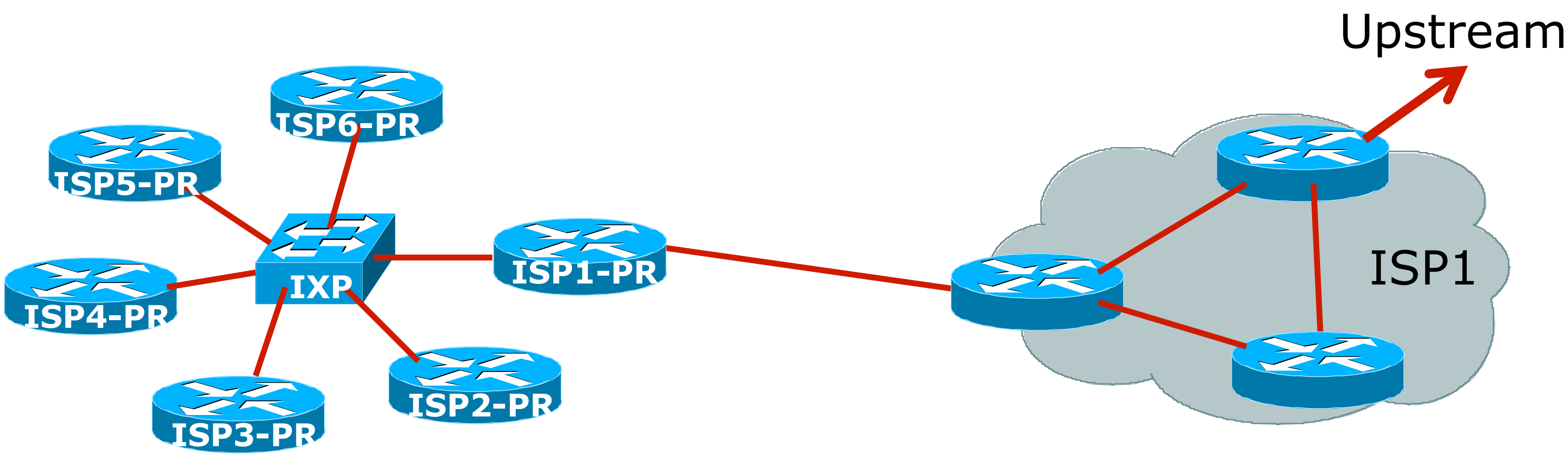


- PR = peering router
  - Runs iBGP (internal) and eBGP (with peer)
  - No default route
  - No "full BGP table"
  - Domestic prefixes only
- Peering router used for all private interconnects

Public Interconnection

- Service provider participates in an Internet Exchange Point
  - It exchanges prefixes it originates into the routing system with the participants of the IXP
  - It chooses who to peer with at the IXP
    - Bi-lateral peering (like private interconnect)
    - Multi-lateral peering (via IXP's route server)
  - It provides the router at the IXP and provides the connectivity from their PoP to the IXP
  - The IXP router carries only domestic prefixes

Public Interconnection



- ISP1-PR = peering router of our ISP
  - Runs iBGP (internal) and eBGP (with IXP peers)
  - No default route
  - No "full BGP table"
  - Domestic prefixes only
- Physically located at the IXP

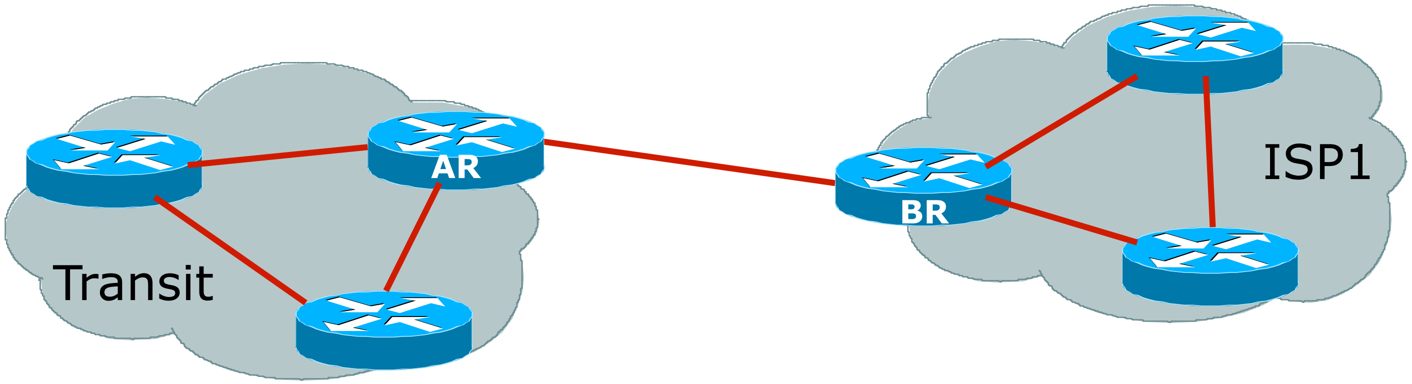
Public Interconnection

- The ISP's router IXP peering router needs careful configuration:
  - It is remote from the domestic backbone
  - Should not originate any domestic prefixes
  - (As well as no default route, no full BGP table)
  - Filtering of BGP announcements from IXP peers (in and out)

Upstream/Transit Connection

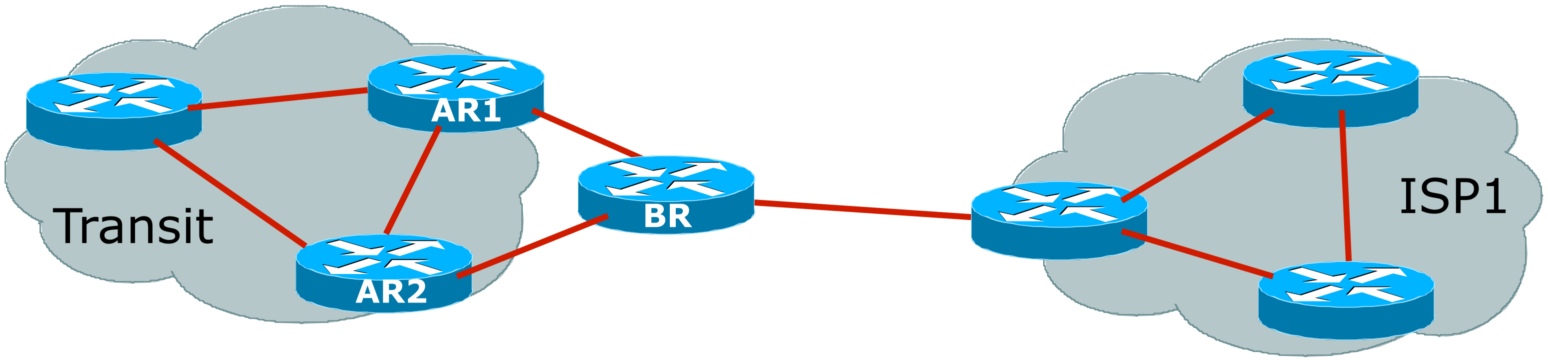
- Two scenarios:
  - Transit provider is in the locality
    - Which means bandwidth is cheap, plentiful, easy to provision, and easily upgraded
  - Transit provider is a long distance away
    - Over undersea cable, satellite, long-haul cross country fibre, etc
- Each scenario has different considerations which need to be accounted for

Local Transit Provider



- BR = ISP's Border Router
  - Runs iBGP (internal) and eBGP (with transit)
  - Either receives default route or the full BGP table from upstream
  - BGP policies are implemented here (depending on connectivity)
  - Packet filtering is implemented here (as required)

Distant Transit Provider



- BR = ISP's Border Router
  - Co-located in a co-lo centre (typical) or in the upstream provider's premises
  - Runs iBGP with rest of ISP1 backbone
  - Runs eBGP with transit provider router(s)
  - Implements BGP policies, packet filtering, etc
  - Does not originate any domestic prefixes

Distant Transit Provider

- Positioning a router close to the Transit Provider’s infrastructure is strongly encouraged:
  - Long haul circuits are expensive, so the router allows the ISP to implement appropriate filtering first
  - Moves the buffering problem away from the Transit provider
  - Remote co-lo allows the ISP to choose another transit provider and migrate connections with minimum downtime

Distant Transit Provider

- Other points to consider:
  - Does require remote hands support
  - (Remote hands would plug or unplug cables, power cycle equipment, replace equipment, etc as instructed)
  - Appropriate support contract from equipment vendor(s)
  - Sensible to consider two routers and two long-haul links for redundancy

Summary

- Design considerations for:
  - Private interconnects
    - Simple private peering
  - Public interconnects
    - Router co-lo at an IXP
  - Local transit provider
    - Simple upstream interconnect
  - Long distance transit provider
    - Router remote co-lo at datacentre or Transit premises

Addressing

Getting IPv4 & IPv6 address space

- Take part of upstream ISP's PA space

  or

- Become a member of your Regional Internet Registry and get your own allocation
  - Require a plan for a year ahead
  - General policies are outlined in RFC2050, more specific details are on the individual RIR website
- There is no more IPv4 address space at IANA
  - APNIC is now in its "final /8" IPv4 delegation policy
  - Limited IPv4 available
  - IPv6 allocations are simple to get in most RIR regions

What about RFC1918 addressing?

- RFC1918 defines IPv4 addresses reserved for private Internets
  - Not to be used on Internet backbones
  - **http://www.ietf.org/rfc/rfc1918.txt**
- Commonly used within end-user networks
  - NAT used to translate from private internal to public external addressing
  - Allows the end-user network to migrate ISPs without a major internal renumbering exercise
- Most ISPs filter RFC1918 addressing at their network edge
  - **http://www.cymru.com/Documents/bogon-list.html**

What about RFC1918 addressing?

- There is a long list of well known problems:
  - http://datatracker.ietf.org/doc/draft-ietf-grow-private-ip-sp-cores
- Including:
  - False belief it conserves address space
  - Adverse effects on Traceroute
  - Effects on Path MTU Discovery
  - Unexpected interactions with some NAT implementations
  - Interactions with edge anti-spoofing techniques
  - Peering using loopbacks
  - Adverse DNS Interaction
  - Serious Operational and Troubleshooting issues
  - Security Issues
    - false sense of security, defeating existing security techniques

What about RFC1918 addressing?

- Infrastructure Security: not improved by using private addressing
  - Still can be attacked from inside, or from customers, or by reflection techniques from the outside
- Troubleshooting: made an order of magnitude harder
  - No Internet view from routers
  - Other ISPs cannot distinguish between down and broken
- Summary:
  - ALWAYS use globally routable IP addressing for ISP Infrastructure

Addressing Plans – ISP Infrastructure

- Address block for router loop-back interfaces
- Address block for infrastructure
  - Per PoP or whole backbone
  - Summarise between sites if it makes sense
  - Allocate according to genuine requirements, not historic classful boundaries
- Similar allocation policies should be used for IPv6 as well
  - ISPs just get a substantially larger block (relatively) so assignments within the backbone are easier to make

Addressing Plans – Customer

- Customers are assigned address space according to need
- Should not be reserved or assigned on a per PoP basis
  - ISP iBGP carries customer nets
  - Aggregation not required and usually not desirable

Addressing Plans (contd)

- Document infrastructure allocation
  - Eases operation, debugging and management
- Document customer allocation
  - Contained in iBGP
  - Eases operation, debugging and management
  - Submit network object to RIR Database

Routing Protocols

Routing Protocols

- IGP – Interior Gateway Protocol
  - carries infrastructure addresses, point-to-point links
  - examples are OSPF, ISIS,...
- EGP – Exterior Gateway Protocol
  - carries customer prefixes and Internet routes
  - current EGP is BGP version 4
- No connection between IGP and EGP

Why Do We Need an IGP?

- ISP backbone scaling
  - Hierarchy
  - Modular infrastructure construction
  - Limiting scope of failure
  - Healing of infrastructure faults using dynamic routing with fast convergence

Why Do We Need an EGP?

- Scaling to large network
  - Hierarchy
  - Limit scope of failure
- Policy
  - Control reachability to prefixes
  - Merge separate organizations
  - Connect multiple IGPs

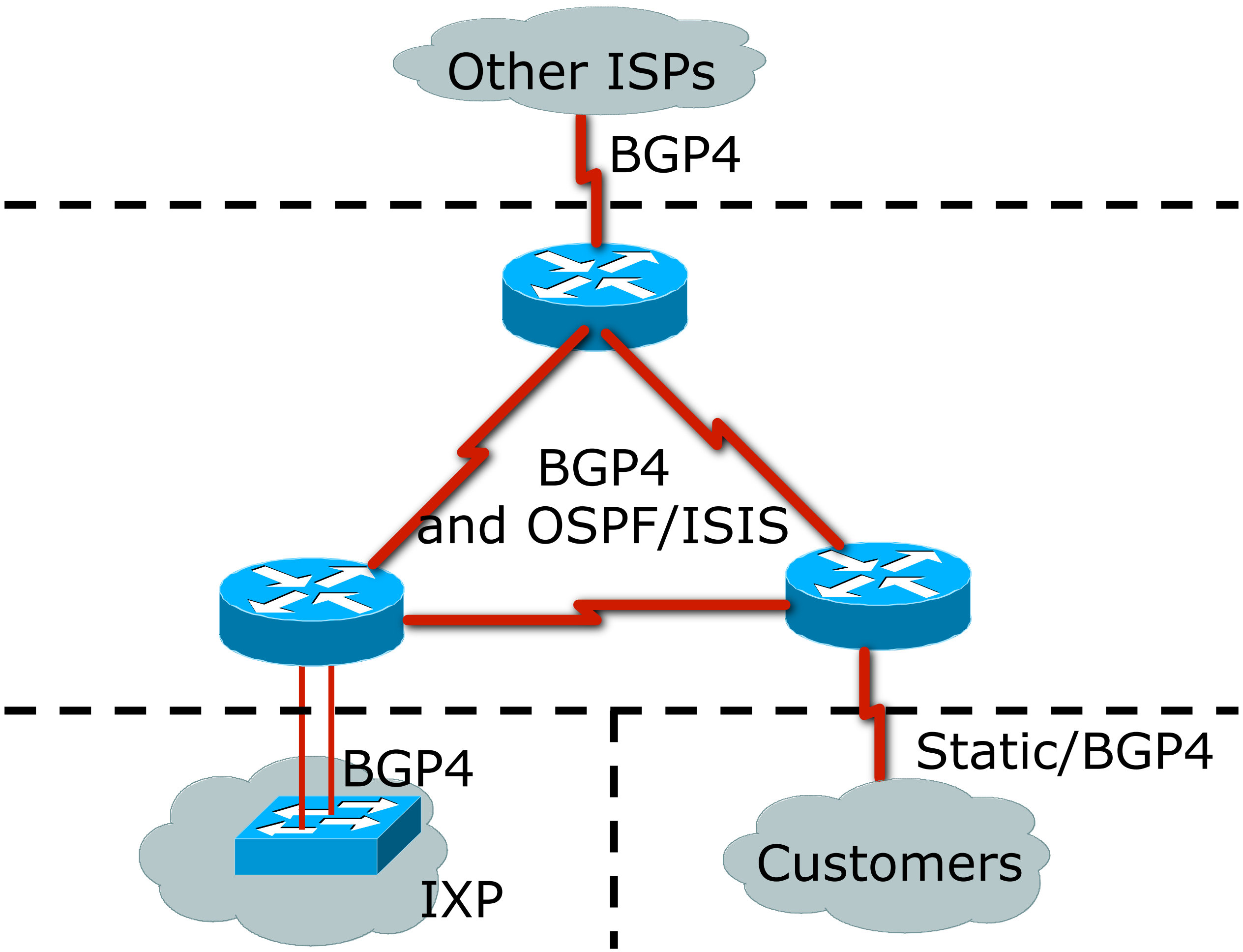
Interior versus Exterior Routing Protocols

- Interior
  - Automatic neighbour discovery
  - Generally trust your IGP routers
  - Prefixes go to all IGP routers
  - Binds routers in one AS together
- Exterior
  - Specifically configured peers
  - Connecting with outside networks
  - Set administrative boundaries
  - Binds AS's together

Interior versus Exterior Routing Protocols

- Interior
  - Carries ISP infrastructure addresses only
  - ISPs aim to keep the IGP small for efficiency and scalability
- Exterior
  - Carries customer prefixes
  - Carries Internet prefixes
  - EGPs are independent of ISP network topology

Hierarchy of Routing Protocols



Routing Protocols: Choosing an IGP

- OSPF and ISIS have very similar properties
- Which to choose?
  - Choose which is appropriate for your operators' experience
  - In most vendor releases, both OSPF and ISIS have sufficient "nerd knobs" to tweak the IGP's behaviour
  - OSPF runs on IP
  - ISIS runs on infrastructure, alongside IP
  - ISIS supports both IPv4 and IPv6
  - OSPFv2 (IPv4) **plus** OPSFv3 (IPv6)

Routing Protocols: IGP Recommendations

- Keep the IGP routing table as small as possible
  - If you can count the routers and the point to point links in the backbone, that total is the number of IGP entries you should see
- IGP details:
  - Should only have router loopbacks, backbone WAN point-to-point link addresses, and network addresses of any LANs having an IGP running on them
  - Strongly recommended to use inter-router authentication
  - Use inter-area summarisation if possible

Routing Protocols: More IGP recommendations

- To fine tune IGP table size more, consider:
  - Using "ip unnumbered" on customer point-to-point links – saves carrying that /30 in IGP
    - (If customer point-to-point /30 is required for monitoring purposes, then put this in iBGP)
  - Use contiguous addresses for backbone WAN links in each area – then summarise into backbone area
  - Don't summarise router loopback addresses – as iBGP needs those (for next-hop)
  - Use iBGP for carrying anything which does not contribute to the IGP Routing process

Routing Protocols: iBGP Recommendations

- iBGP should carry everything which doesn’t contribute to the IGP routing process
  - Internet routing table
  - Customer assigned addresses
  - Customer point-to-point links
  - Dial network pools, passive LANs, etc

Routing Protocols: More iBGP Recommendations

- Scalable iBGP features:
  - Use neighbour authentication
  - Use peer-groups to speed update process and for configuration efficiency
  - Use communities for ease of filtering
  - Use route-reflector hierarchy
    - Route reflector pair per PoP (overlaid clusters)

Out of Band Management

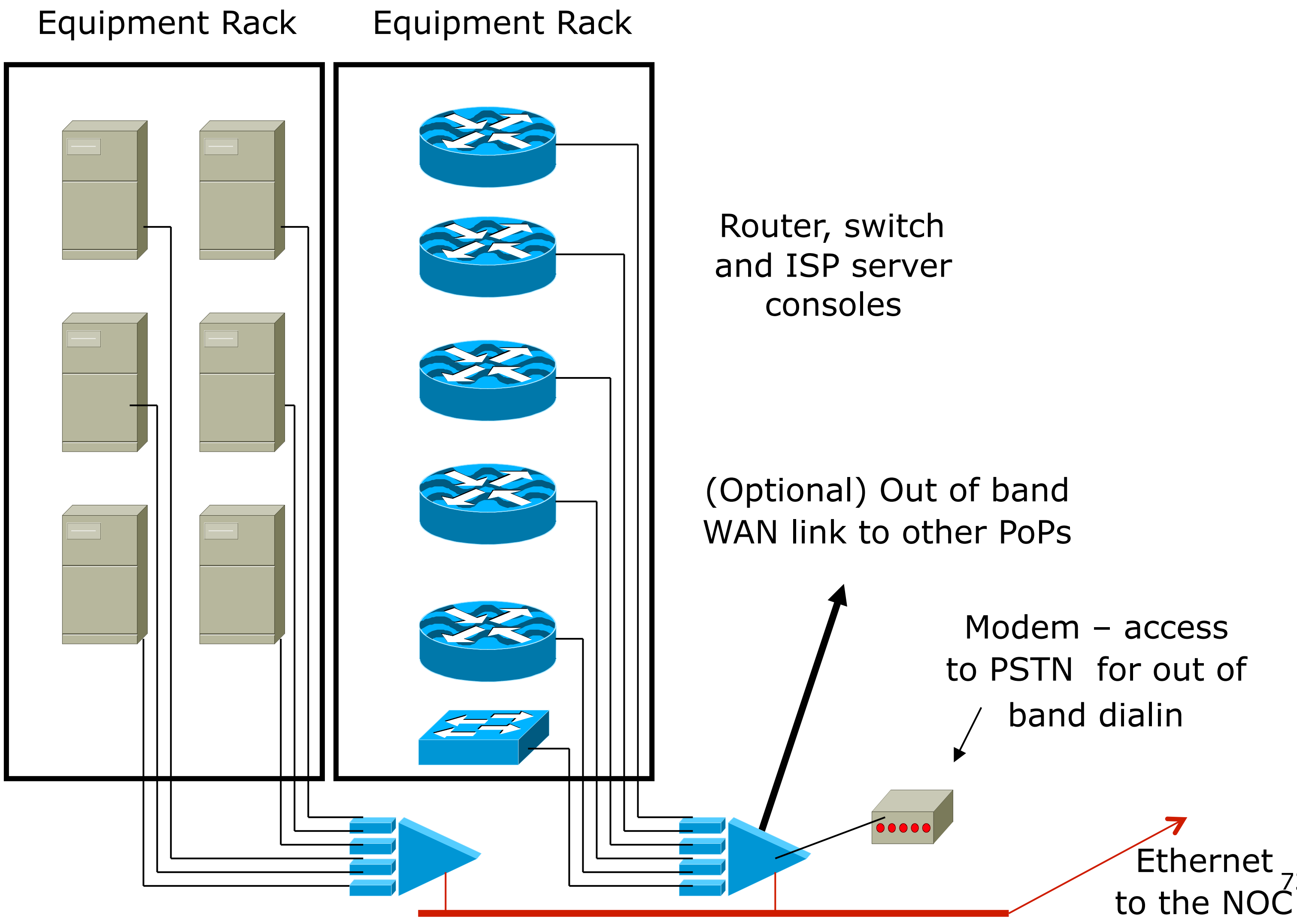
Out of Band Management

- **Not optional!**
- Allows access to network equipment in times of failure
- Ensures quality of service to customers
  - Minimises downtime
  - Minimises repair time
  - Eases diagnostics and debugging

Out of Band Management

- OoB Example – Access server:
  - modem attached to allow NOC dial in
  - console ports of all network equipment connected to serial ports
  - LAN and/or WAN link connects to network core, or via separate management link to NOC
- Full remote control access under all circumstances

Out of Band Network



Out of Band Management

- OoB Example – Statistics gathering:
  - Routers are NetFlow and syslog enabled
  - Management data is congestion/failure sensitive
  - Ensures management data integrity in case of failure
- Full remote information under all circumstances

Test Laboratory

Test Laboratory

- Designed to look like a typical PoP
  - Operated like a typical PoP
- Used to trial new services or new software under realistic conditions
- Allows discovery and fixing of potential problems before they are introduced to the network

Test Laboratory

- Some ISPs dedicate equipment to the lab
- Other ISPs "purchase ahead" so that today's lab equipment becomes tomorrow's PoP equipment
- Other ISPs use lab equipment for "hot spares" in the event of hardware failure

Test Laboratory

- Can't afford a test lab?
  - Set aside one spare router and server to trial new services
  - Never ever try out new hardware, software or services on the live network
- Every major ISP in the US and Europe has a test lab
  - It's a serious consideration

Operational Considerations

Operational Considerations

Why design the world's best network when you have not thought about what operational good practices should be implemented?

Operational Considerations
Maintenance

- Never work on the live network, no matter how trivial the modification may seem
  - Establish maintenance periods which your customers are aware of
    - e.g. Tuesday 4-7am, Thursday 4-7am
- Never do maintenance on a Friday
  - Unless you want to work all weekend cleaning up
- Never do maintenance on a Monday
  - Unless you want to work all weekend preparing

Operational Considerations
Support

- Differentiate between customer support and the Network Operations Centre
  - Customer support fixes customer problems
  - NOC deals with and fixes backbone and Internet related problems
- Network Engineering team is last resort
  - They design the next generation network, improve the routing design, implement new services, etc
  - They do not and should not be doing support!

Operational Considerations
NOC Communications

- NOC should know contact details for equivalent NOCs in upstream providers and peers

ISP Network Design

Summary

ISP Design Summary

- KEEP IT SIMPLE & STUPID ! (KISS)
- Simple is elegant is scalable
- Use Redundancy, Security, and Technology to make life easier for yourself
- Above all, ensure quality of service for your customers

Why an Internet Exchange Point?

Saving money, improving QoS, Generating a local Internet economy

Internet Exchange Point
Why peer?

- Consider a region with one ISP
  - They provide internet connectivity to their customers
  - They have one or two international connections
- Internet grows, another ISP sets up in competition
  - They provide internet connectivity to their customers
  - They have one or two international connections
- How does traffic from customer of one ISP get to customer of the other ISP?
  - Via the international connections

Internet Exchange Point
Why peer?

- Yes, International Connections…
  - If satellite, RTT is around 550ms per hop
  - So local traffic takes over 1s round trip
- International bandwidth
  - Costs significantly more than domestic bandwidth
  - Congested with local traffic
  - Wastes money, harms performance

Internet Exchange Point
Why peer?

- Solution:
  - Two competing ISPs peer with each other
- Result:
  - Both save money
  - Local traffic stays local
  - Better network performance, better QoS,…
  - More international bandwidth for expensive international traffic
  - Everyone is happy

Internet Exchange Point
Why peer?

- A third ISP enters the equation
  - Becomes a significant player in the region
  - Local and international traffic goes over their international connections
- They agree to peer with the two other ISPs
  - To save money
  - To keep local traffic local
  - To improve network performance, QoS,…

Internet Exchange Point
Why peer?

- Peering means that the three ISPs have to buy circuits between each other
  - Works for three ISPs, but adding a fourth or a fifth means this does not scale
- Solution:
  - Internet Exchange Point

Internet Exchange Point

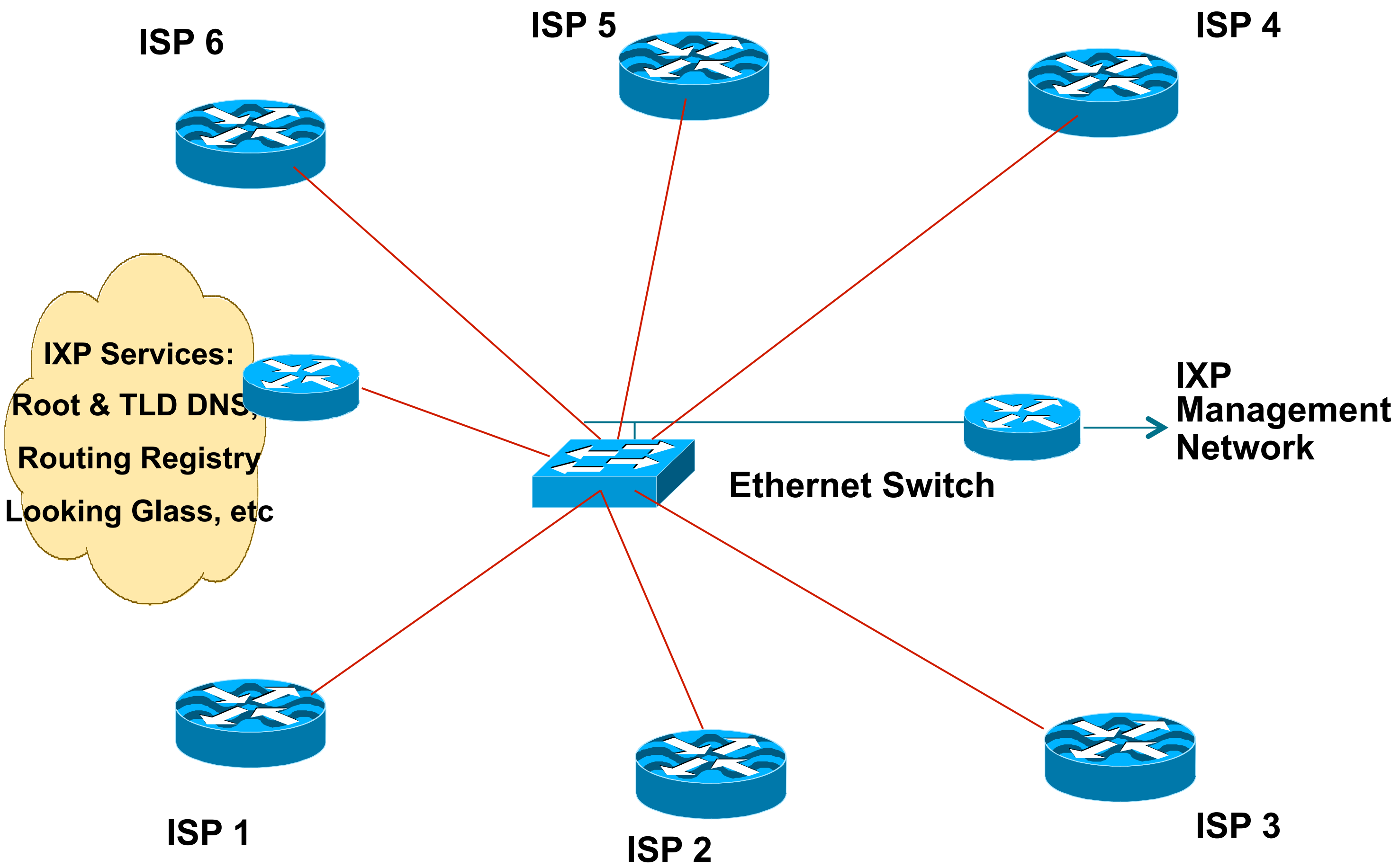
- Every participant has to buy just one whole circuit
  - From their premises to the IXP
- Rather than N-1 half circuits to connect to the N-1 other ISPs
  - 5 ISPs have to buy 4 half circuits = 2 whole circuits → already twice the cost of the IXP connection

Internet Exchange Point

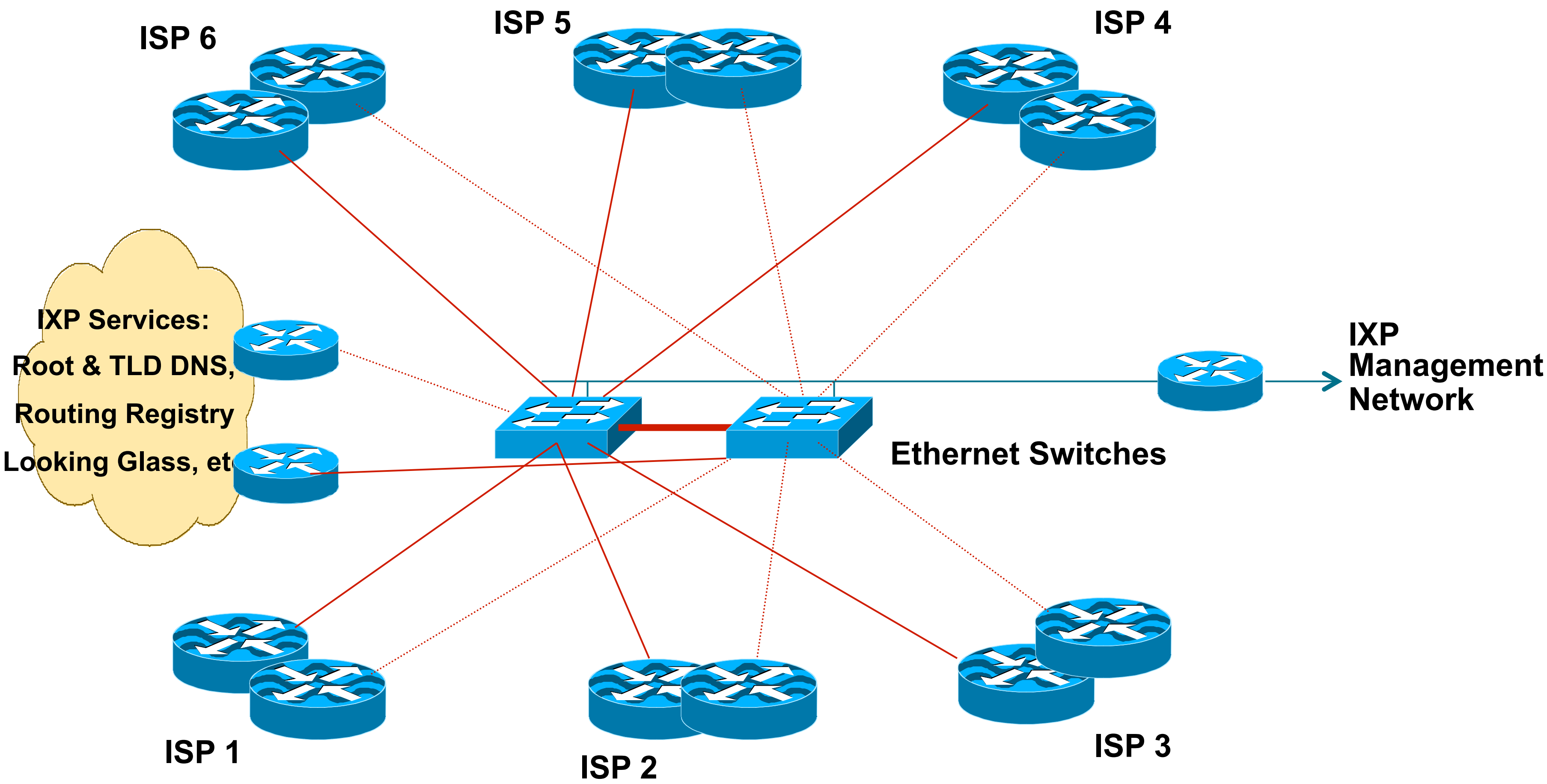
- Solution
  - Every ISP participates in the IXP
  - Cost is minimal – one local circuit covers all domestic traffic
  - International circuits are used for just international traffic – and backing up domestic links in case the IXP fails
- Result:
  - Local traffic stays local
  - QoS considerations for local traffic is not an issue
  - RTTs are typically sub 10ms
  - Customers enjoy the Internet experience
  - Local Internet economy grows rapidly

Exchange Point Design

Layer 2 Exchange



Layer 2 Exchange



Layer 2 Exchange

- Two switches for redundancy
- ISPs use dual routers for redundancy or loadsharing
- Offer services for the "common good"
  - Internet portals and search engines
  - DNS Root & TLD, NTP servers
  - Routing Registry and Looking Glass

Layer 2 Exchange

- Requires neutral IXP management
  - Usually funded equally by IXP participants
  - 24x7 cover, support, value add services
- Secure and neutral location
- Configuration
  - IPv4 /24 and IPv6 /64 for IXP LAN
  - ISPs require AS, basic IXP does not

Layer 2 Exchange

- Network Security Considerations
  - LAN switch needs to be securely configured
  - Management routers require TACACS+ authentication, vty security
  - IXP services must be behind router(s) with strong filters

"Layer 3 IXP"

- Layer 3 IXP is marketing concept used by Transit ISPs
- Real Internet Exchange Points are only Layer 2

IXP Design Considerations

Exchange Point Design

- The IXP Core is an Ethernet switch
- Has superseded all other types of network devices for an IXP
  - From the cheapest and smallest 12 or 24 port 10/100 switch
  - To the largest 192 port 10GigEthernet switch

Exchange Point Design

- Each ISP participating in the IXP brings a router to the IXP location
- Router needs:
  - One Ethernet port to connect to IXP switch
  - One WAN port to connect to the WAN media leading back to the ISP backbone
  - To be able to run BGP

Exchange Point Design

- IXP switch located in one equipment rack dedicated to IXP
  - Also includes other IXP operational equipment
- Routers from participant ISPs located in neighbouring/adjacent rack(s)
- Copper (UTP) connections made for 10Mbps, 100Mbps or 1Gbps connections
- Fibre used for 10Gbps, 40Gbps or 100Gbps connections

Peering

- Each participant needs to run BGP
  - They need their own AS number
  - **Public** ASN, **NOT** private ASN
- Each participant configures external BGP directly with the other participants in the IXP
  - Peering with all participants

    or
  - Peering with a subset of participants

Peering (more)

- Mandatory Multi-Lateral Peering (MMLP)
  - Each participant is required to peer with every other participant as part of their IXP membership
  - **Has no history of success** — the practice is strongly discouraged
- Multi-Lateral Peering (MLP)
  - Each participant peers with every other participant (usually aided by a Route Server)
- Bi-Lateral Peering
  - Participants set up peering with each other according to their own requirements and business relationships
  - This is the most common situation at IXPs today

Routing

- ISP border routers at the IXP generally should NOT be configured with a default route or carry the full Internet routing table
  - Carrying default or full table means that this router and the ISP network is open to abuse by non-peering IXP members
  - Correct configuration is only to carry routes offered to IXP peers on the IXP peering router
- Note: Some ISPs offer transit across IX fabrics
  - They do so at their own risk – see above

Routing (more)

- ISP border routers at the IXP should not be configured to carry the IXP LAN network within the IGP or iBGP
  - Use next-hop-self BGP concept
- Don’t generate ISP prefix aggregates on IXP peering router
  - If connection from backbone to IXP router goes down, normal BGP failover will then be successful

Address Space

- Some IXPs use private addresses for the IX LAN
  - Public address space means IXP network could be leaked to Internet which may be undesirable
  - Because most ISPs filter RFC1918 address space, this avoids the problem
- Some IXPs use public addresses for the IX LAN
  - Address space available from the RIRs
  - IXP terms of participation often forbid the IX LAN to be carried in the ISP member backbone

Services Offered

- Services offered should not compete with member ISPs (basic IXP)
  - e.g. web hosting at an IXP is a bad idea unless all members agree to it
- IXP operations should make performance and throughput statistics available to members
  - Use tools such as MRTG/Cacti to produce IX throughput graphs for member (or public) information

Services to Offer

- ccTLD DNS
  - the country IXP could host the country's top level DNS
  - e.g. "SE." TLD is hosted at Netnod IXes in Sweden
  - Offer back up of other country ccTLD DNS
- Root server
  - Anycast instances of I.root-servers.net, F.root-servers.net etc are present at many IXes
- Usenet News
  - Usenet News is high volume
  - could save bandwidth to all IXP members

Services to Offer

- Route Collector
  - Route collector shows the reachability information available at the exchange
- Looking Glass
  - One way of making the Route Collector routes available for global view (e.g. www.traceroute.org)
  - Public or members only access

Services to Offer

- Content Redistribution/Caching
  - For example, Akamised update distribution service
- Network Time Protocol
  - Locate a stratum 1 time source (GPS receiver, atomic clock, etc) at IXP
- Routing Registry
  - Used to register the routing policy of the IXP membership

Conclusion

- IXPs are technically very simple to set up
- Little more than:
  - An ethernet switch
  - Neutral secure reliable location
  - Consortium of members to operate it
- Political aspects can be more challenging:
  - Competition between ISP members
  - "ownership" or influence by outside parties