Washington University in St. Louis

Engineering

15. Inter-Domain Routing

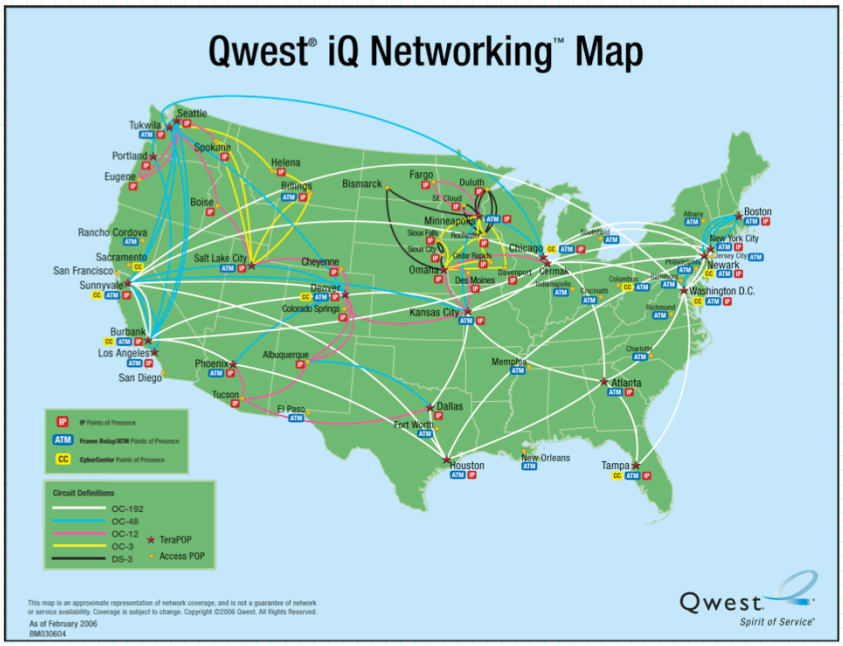
- General Concepts
- BGP

Jon Turner – slides adapted from Kurose and Ross

Hierarchical Routing

- The Internet is divided among many distinct networks
  - » owned and operated by different organizations
  - » networks called *Autonomous Systems* (aka routing domains)
- Leads to a two level routing structure
  - » intra-domain routing: finding most efficient paths within an AS
  - » inter-domain routing: finding paths among ASes
  - » makes Internet routing more scalable
  - » allows ASes to operate independently and to keep their internal network structure private
- Drawbacks of hierarchical routing
  - » lack of global knowledge of network topology prevents selection of best routes
  - » motivates AS-owners to focus on reducing their own costs, not providing best service to users

2


Qwest® iQ Networking™ Map
Seattle
Tukwila
Portland
Eugene
Spokane
Helena
Billings
Bismarck
Fargo
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St. Cloud
Minneapolis
Boise
Rancho Cordova
Sacramento
San Francisco
Sunnyvale
Salt Lake City
Cheyenne
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Des Moines
Chicago
Denver
Colorado Springs
Kansas City
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Boston
New York City
Jersey City
Newark
Washington D.C.
Burbank
Los Angeles
San Diego
Phoenix
Albuquerque
Tucson
El Paso
Dallas
Fort Worth
Houston
Memphis
Atlanta
New Orleans
Tampa
IP IP Points of Presence
ATM Frame Relay/ATM Points of Presence
CC CyberCenter Points of Presence
Circuit Definitions
OC-192
OC-48
OC-12
OC-3
DS-3
TeraPOP
Access POP
This map is an approximate representation of network coverage, and is not a guarantee of network or service availability. Coverage is subject to change. Copyright ©2006 Qwest. All Rights Reserved.
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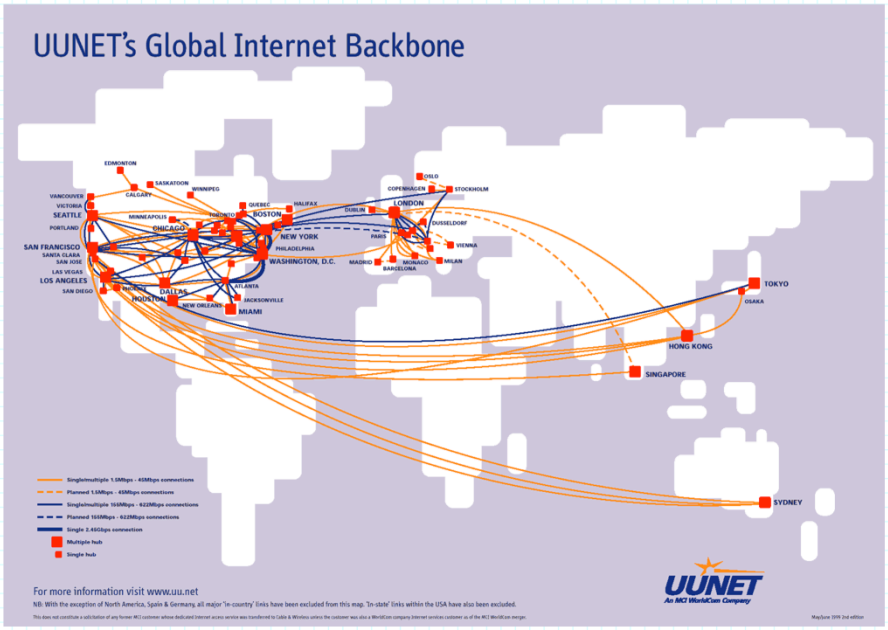
UUNET's Global Internet Backbone
EDMONTON
SASKATOON
CALGARY
WINNIPEG
VANCOUVER
VICTORIA
SEATTLE
PORTLAND
SAN FRANCISCO
SANTA CLARA
SAN JOSE
LAS VEGAS
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MINNEAPOLIS
CHICAGO
TORONTO
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HALIFAX
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VIENNA
MADRID
MONACO
BARCELONA
MILAN
TOKYO
OSAKA
HONG KONG
SINGAPORE
SYDNEY
Single/multiple 1.5Mbps - 45Mbps connections
Planned 1.5Mbps - 45Mbps connections
Single/multiple 155Mbps - 622Mbps connections
Planned 155Mbps - 622Mbps connections
Single 2.4Gbps connection
Multiple hub
Single hub
For more information visit www.uu.net
NB: With the exception of North America, Spain & Germany, all major 'in-country' links have been excluded from this map. 'In-state' links within the USA have also been excluded.
This does not constitute a solicitation of any former MCI customer whose dedicated Internet access service was transferred to Cable & Wireless unless the customer was also a WorldCom company Internet services customer as of the MCI WorldCom merger.
May/June 1999 2nd edition
UUNET
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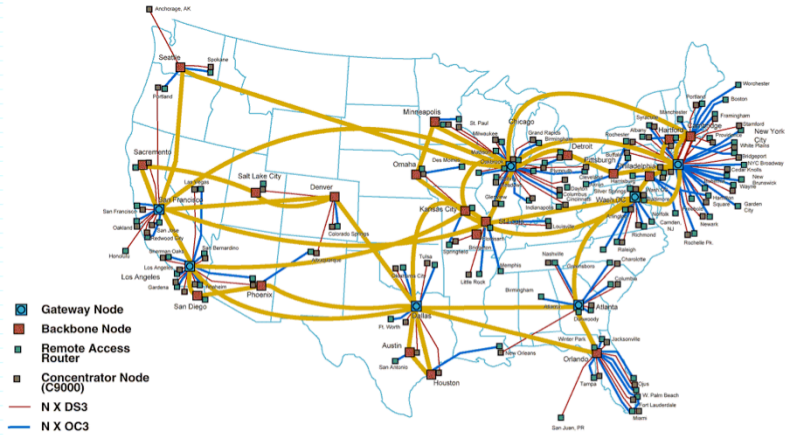
AT&T

AT&T IP BACKBONE NETWORK

2Q2000



Note: map is not to scale.

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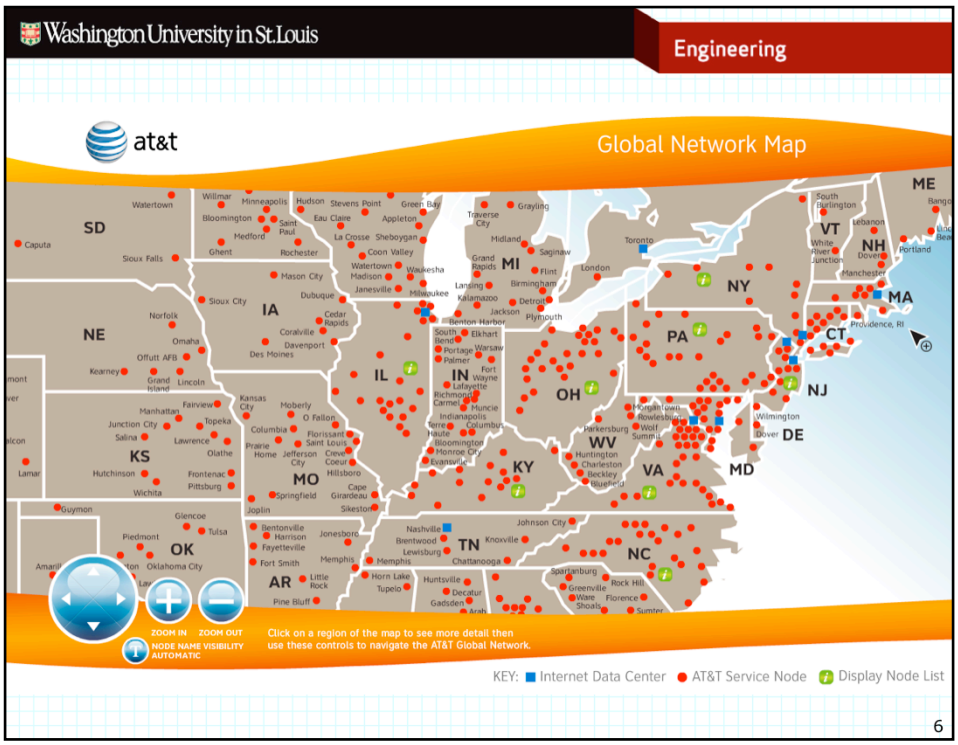
Washington University in St.Louis
Engineering
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Global Network Map
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ZOOM IN
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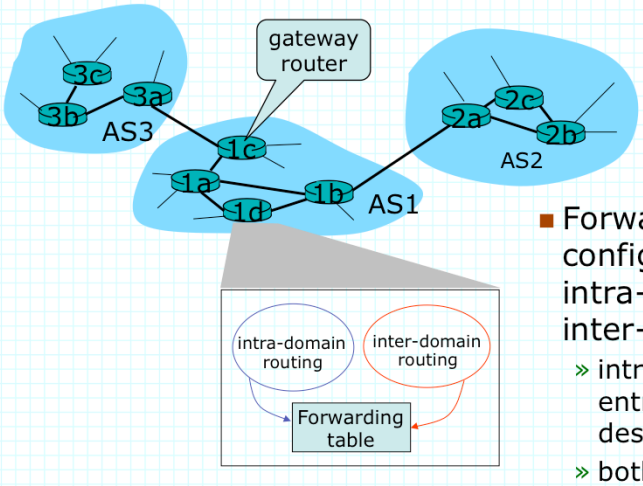
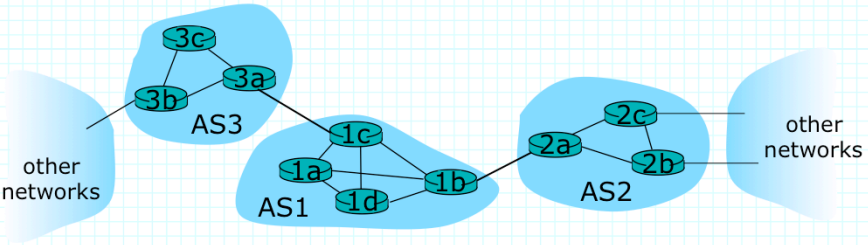
NODE NAME VISIBILITY AUTOMATIC
Click on a region of the map to see more detail then use these controls to navigate the AT&T Global Network.
KEY: Internet Data Center AT&T Service Node Display Node List
6

Intra-Domain & Inter-Domain Routing



- Forwarding table configured by both intra-domain and inter-domain routing
  - » intra-domain sets entries for internal destinations
  - » both collaborate to set entries for external destinations

Inter-AS Tasks



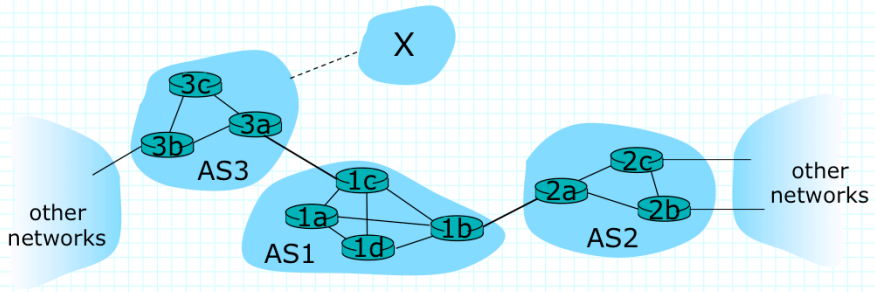
- Suppose router in AS1 receives datagram destined outside of AS1
  - » router should forward packet to gateway router, but which one?

AS1 must:

1. learn which destinations are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1

8

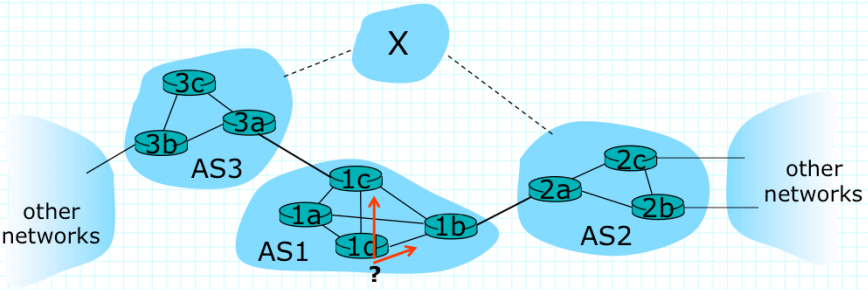
Setting Forwarding Table in Router 1d



- Suppose AS1 learns (via inter-domain protocol) that *X* is reachable via AS3 (gateway 1c) but not via AS2
  - » inter-domain protocol propagates reachability info to all internal routers
- Router 1d determines from intra-domain routing info that its interface *I* is on the least cost path to 1c
  - » installs forwarding table entry (*X,I*)

9

Choosing Among Multiple Paths



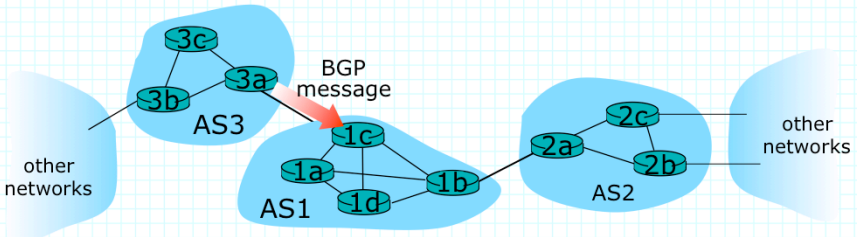
- Now suppose AS1 learns from inter-domain protocol that subnet *x* is reachable from AS3 *and* from AS2
- To configure forwarding table, router 1d must select from among multiple choices
  - » common approach, choose path with fewest AS-hops
    - break ties by picking closest gateway
    - may not be the true least-cost path

Internet Inter-Domain Routing: BGP

- BGP (Border Gateway Protocol): *the* de facto inter-domain routing protocol
  - "glue that holds the Internet together"
- BGP provides each AS a means to:
  - obtain subnet reachability information from neighboring ASs – eBGP
  - propagate reachability information to all AS-internal routers – iBGP
  - determine "good" routes to other networks based on reachability information and policy.
- Allows subnet to advertise its existence to rest of Internet

BGP Basics

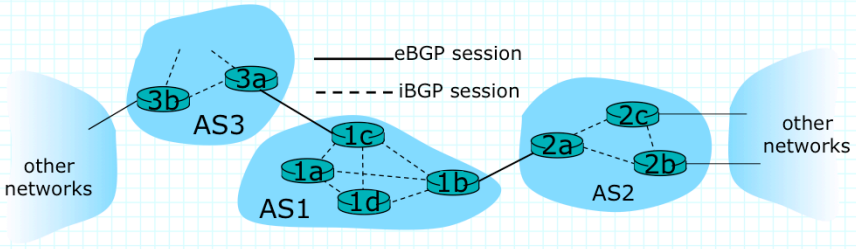
- BGP session – two BGP routers ("peers") exchange BGP messages
  - » advertising *paths* to different destination network prefixes ("path vector" protocol)
  - » exchanged over semi-permanent TCP connections
- Example: if AS3 advertises a prefix 1.2.0.0/16 to AS1
  - » AS3 *promises* it will forward matching datagrams from AS1
  - » AS3 can *aggregate* prefixes in its advertisements



12

Distributing Path Information

- Using eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1
  - » 1c can then use iBGP to distribute new prefix info to all routers in AS1
  - » 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- When router learns of new prefix, it creates entry for prefix in its forwarding table



Path Attributes and BGP Routes

- Advertised prefix includes BGP attributes
  - » prefix + attributes = "route"
- Two important attributes:
  - » AS-PATH: contains ASs through which prefix advertisement has passed: e.g., AS 67, AS 17
  - » NEXT-HOP: indicates specific internal-AS router to next-hop AS (may be multiple links from current router to next-hop-AS)
- Gateway router receiving route advertisement uses *import policy* to accept/decline
  - » for example, an AS may choose to not route transit traffic to domains that are not its "customers"
  - » *policy-based* routing

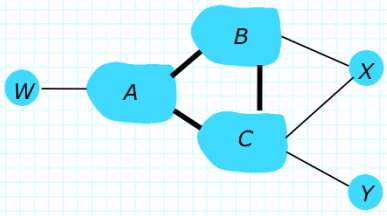
BGP Route Selection

- Router may learn about more than 1 route to destination AS, selects route based on:
  1. local preference value attribute: policy decision
  2. shortest AS-PATH
     - no essential relationship to user-perceived performance
  3. closest NEXT-HOP router: hot potato routing
  4. additional criteria

BGP Messages

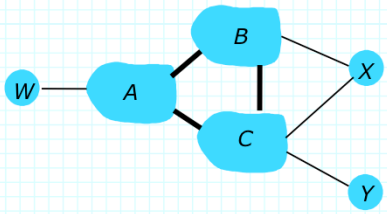
- BGP messages exchanged between peers over TCP connection
- BGP messages
  - » OPEN – opens TCP connection to peer and authenticates sender
  - » UPDATE – advertises new path (or withdraws old)
  - » KEEPALIVE – keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - » NOTIFICATION – reports errors in previous message; also used to close connection

BGP Routing Policy



- *A*, *B*, *C* are provider networks
- *X*, *W*, *Y* are customera (of provider networks)
- *X* is dual-homed: attached to two provider networks
  - » *X* does not want to route from *B* via *X* to *C*
  - » .. so *X* will not advertise to *B* a route to *C*

BGP Routing Policy



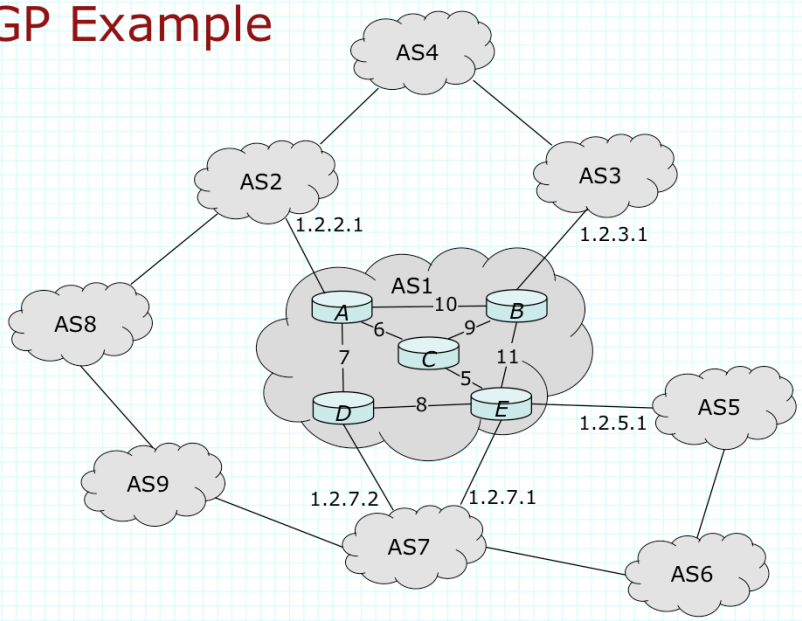
- *A* advertises path *AW* to *B*
- *B* advertises path *BAW* to *X*
- Should *B* advertise path *BAW* to *C*?
  - » No way! *B* gets no "revenue" for routing *CBAW* since neither *W* nor *C* are *B*'s customers
  - » *B* wants to force *C* to route to *w* via *A*
  - » *B* wants to route only to/from its customers!
  - » unless *B* and *C* agree to forward traffic for each other (peering)

18

Why Use Different Routing Protocols?

- Policy
  - » Inter-domain: administrator wants control over how its traffic is routed and who routes through its net
  - » Intra-domain: single admin, so no policy decisions needed
- Scale
  - » hierarchical routing reduces table size and update traffic
    - arguably, modern processors can handle internet scale
- Performance
  - » Intra-domain: can focus on performance
  - » Inter-domain: policy may dominate over performance
- Drawbacks
  - » independent policy choices can lead to routing instability
  - » inter-domain routing largely ignores user-perceived performance

BGP Example


AS4
AS2
AS3
1.2.2.1
1.2.3.1
AS1
A
B
C
D
E
10
6
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11
5
8
AS8
AS5
1.2.5.1
AS9
1.2.7.2
1.2.7.1
AS7
AS6

Exercises

Assume BGP when answering the following questions.

1. List five distinct inter-AS paths leading to AS4 that router *C* might learn of using BGP. For each path, give the path and the "next-hop-address" for that path. For each of these inter-AS paths, what is the intra-AS path that would be used with it? Which path would you expect it to actually select?
2. What path would router *B* use to reach AS8? What path would it use to reach AS9?
3. How could AS1 avoid carrying packets between AS2 and AS7? Might this have some unintended consequences?

Exercises

1. Give an example illustrating how the routes computed by BGP can lead to packets traveling distances that are much longer than the shortest path distance between the sender and the receiver. How common do you think such sub-optimal paths are? What are some of the negative consequences of packets taking sub-optimal paths?
2. One justification for BGP's AS-hop-based metric is that it allows ISPs to conceal the topologies of their networks. Why do you think ISPs consider it important to keep this information secret? Do you think that these reasons are sufficient justification for the negative impacts of sub-optimal routing?