Implementation

Major Internet routing protocols:

• RIP (v1 and v2): intra-domain, Bellman-Ford
  → also called “distance vector”
  → metric: hop count
  → UDP
  → nearest neighbor advertisement
  → popular in small intra-domain networks

• OSPF (v1 and v2): intra-domain, Dijkstra
  → also called “link state”
  → metric: average delay
  → directly over IP: protocol number 89
  → broadcasting via flooding
  → popular in larger intra-domain networks
• IS-IS: intra-domain, Dijkstra
  → “link state”
  → directly over link layer (e.g., Ethernet)
  → more recently: also available over IP
  → flooding
  → popular in larger intra-domain networks
BGP (Border Gateway Protocol):

→ inter-domain routing

Autonomous System A       Autonomous System B

→ “peering” between two domains
→ includes customer-provider relationship
→ Internet exchanges: multiple domains
• CIDR addressing
  → i.e., $a.b.c.d/x$
  → Purdue: 128.10.0.0/16, 128.210.0.0/16, 204.52.32.0/20
  → check at www.iana.org (e.g., ARIN for US)

• Metric: policy
  → e.g., shortest-path, trust, pricing
  → meaning of “shortest”: delay, router hop, AS hop
  → mechanism: path vector routing
  → BPG update message
BGP route update:

→ BGP update message propagation

BGP update message:

\[ \text{ASN}_{A_k} \rightarrow \cdots \rightarrow \text{ASN}_{A_2} \rightarrow \text{ASN}_{A_1}; \ a.b.c.d/x \]

Meaning: ASN \( A_1 \) (with CIDR address a.b.c.d/x) can be reached through indicated path

→ “path vector”

→ called AS-PATH

Some AS numbers:

- Purdue: 17
- BBN: 1
- UUNET: 701
- Level3: 3356
- Abilene (aka “Internet2”): 11537
Policy:

- if multiple AS-PATHs to target AS are known, choose one based on policy
  
  → e.g., shortest AS path length, cheapest, least worrisome

- advertise to neighbors target AS’s reachability
  
  → also subject to policy

  → no obligation to advertise

  → specifics depend on bilateral contract (SLA)

SLA (service level agreement):

  → bandwidth (e.g., 1 Gbps, OC-3, DS3)

  → delay (e.g., avrg. 25ms US), loss (e.g., 0.05%)

  → pricing (e.g., 1 Mbps: below $100)

  → availability (e.g., 99.999%)

  → etc.
Ex.:  

```
CS 422 Park

AS F  AS C
    |    |
AS H ———> AS B
     |    |
    AS G ———> AS E

    Provider
      Stub
```

```
AS F  AS C
    |    |
AS H ———> AS B
     |    |
    AS D ———> AS E

    B -> A; a.b.c.d/x
    D -> B -> A; a.b.c.d/x
    G -> D -> B -> A; a.b.c.d/x

Purdue: ASN 17; 128.10.0.0/16
```
Performance

Route update frequency:

→ routing table stability vs. responsiveness

→ rule: not too frequently

→ 30 seconds

→ stability wins

→ hard lesson learned from the past (sub-second)

→ legacy: TTL

Other factors for route instability:

→ selfishness (e.g., fluttering)

→ BGP’s vector path routing: inherently unstable

→ more common: slow convergence

→ target of denial-of-service (DoS) attack
Route amplification:

→ shortest AS path ≠ shortest router path
→ e.g., may be several router hops longer
→ AS graph vs. router graph
→ inter- vs. intra-domain routing: separate subsystems
→ policy: company in Denmark

Route asymmetry:

→ routes are not symmetric
→ estimate: > 50%
→ mainly artifact of inter-domain policy routing
→ various performance implications
→ source traceback
Black holes:

\[\rightarrow\] persistent unreachable destination prefixes

\[\rightarrow\] BGP routing problems

\[\rightarrow\] further aggrevated by DNS

\[\rightarrow\] purely application layer: end system problem