L11: Protocols and Network layer

Frans Kaashoek

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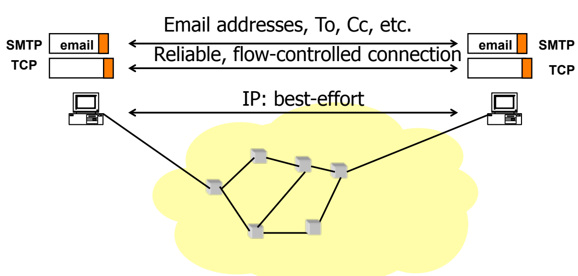
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Internet: Best Effort

No Guarantees:

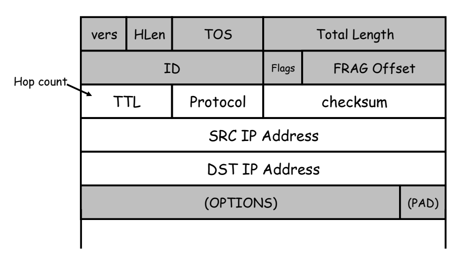
- Variable Delay (jitter)
- Variable rate
- Packet loss
- Duplicates
- Reordering
- Maximum length

End hosts implement everything else



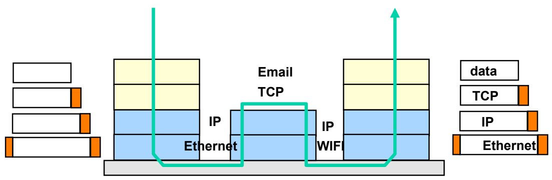
Protocol

- Defines the structure of a conversation
- Typical a sequence of messages, each with its own header
- Examples: DHCP, DNS, UDP, SMTP, TCP, IP, …
- Internet protocols defined in text documents (RFCs)

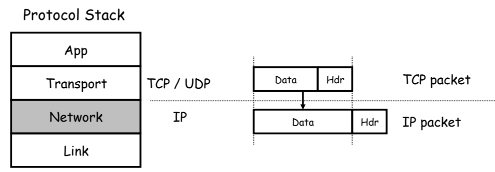


Layering of protocols

- Each layer adds/strips off its own header
- Each layer may split up higher-level data
- Each layer multiplexes multiple higher layers
- Each layer is (mostly) transparent to higher layers



The Internet Stack

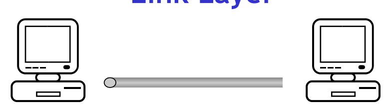


The Internet “Hour glass”

```
App          +------+------+------+------+------+
             |Email | Web  | VoIP | P2P  | RTSP|
             +------+------+------+------+------+
Transport           | TCP  |  UDP | ICMP |
                    +------+------+------+
Network                    |  IP  |
                    +------+------+------+
                    |Ether |Sonet | ATM  |
Link         +------+------+------+------+------+
             |Fiber | TP   | CAT5 | WiFi | GSM  |
             +------+------+------+------+------+
```

"Everything over IP, and IP over everything"

Link Layer



Problem:
Deliver data from one end of the link to the other

Need to address (6.02):
- Bits→ Analog → Bits
- Framing
- Errors
- Medium Access Control

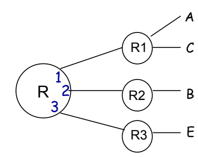
Network Layer:

finds a path to the destination and forwards packets along that path

- Difference between routing and forwarding
  - Routing is finding the path
  - Forwarding is the action of sending the packet to the next-hop toward its destination

Forwarding

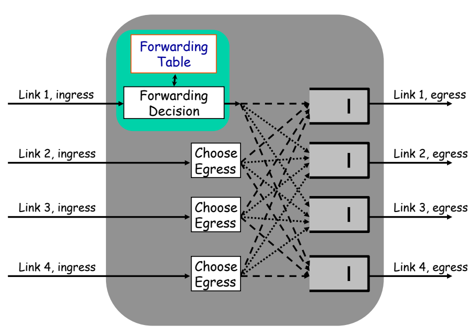
- Each router has a forwarding table
- Forwarding tables are created by a routing protocol



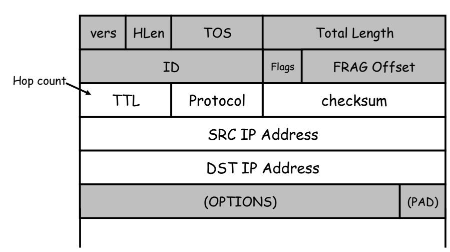
Forwarding table at R

Dst. Addr	Link
A	1
B	2
C	1
E	3

Inside a router



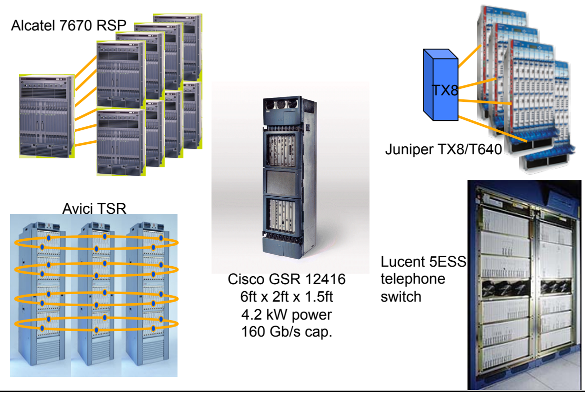
The IP Header



Forwarding an IP Packet

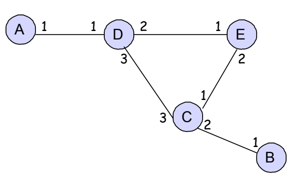
- Lookup packet's DST in forwarding table
  - If known, find the corresponding outgoing link
  - If unknown, drop packet
- Decrement TTL and drop packet if TTL is zero; update header Checksum
- Forward packet to outgoing port
- Transmit packet onto link

And switches today…



The Routing Problem:

- Generate forwarding tables



Goals: No loops, short paths, etc.

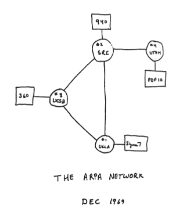
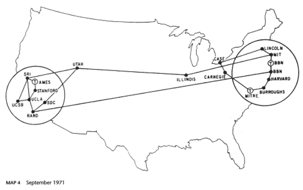
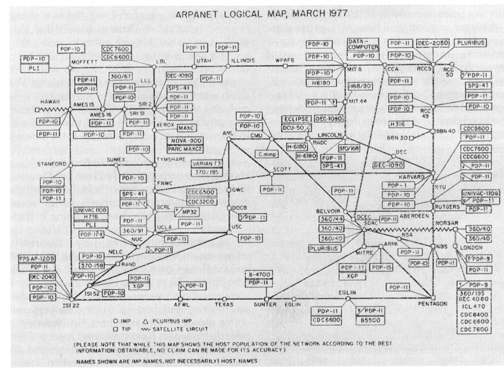
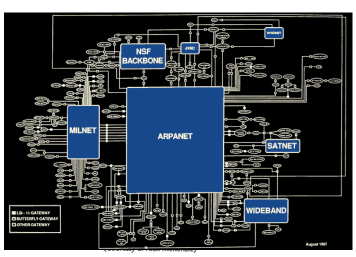


FIGURE 6.2 Drawing of 4 Node Network
(Courtesy of Alex McKenzie)

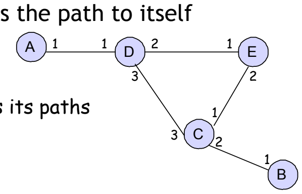






Path Vector Routing Protocol

- Initialization
  - Each node knows the path to itself

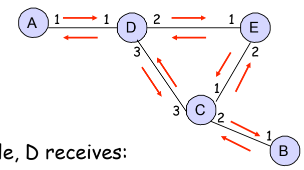


For example, D initializes its paths

DST	Link	Path
D	End layer	null

Path Vector

- Step 1: Advertisement
  - Each node tells its neighbors its path to each node in the graph



For example, D receives:

From A:

To	Path
A	null

From C:

To	Path
C	null

From E:

To	Path
E	null

Path Vector

- Step 2: Update Route Info
  - Each node use the advertisements to update its paths

D received:

From A:

To	Path
A	null

From C:

To	Path
C	null

From E:

To	Path
E	null

D updates its paths:

DST	Link	Path
D	End layer	null

→

DST	Link	Path
D	End layer	null
A	1	<A>
C	3	<C>
E	2	<E>

Note: At the end of first round, each node has learned all one-hop paths

Path Vector

- Periodically repeat Steps 1 & 2

In round 2, D receives:

From A:

To	Path
A	null
D	<D>

From C:

To	Path
C	null
D	<D>
E	<E>
B	<B>

From E:

To	Path
E	null
D	<D>
C	<C>

D updates its paths:

DST	Link	Path
D	End layer	null
A	1	<A>
C	3	<C>
E	2	<E>

→

DST	Link	Path
D	End layer	null
A	1	<A>
C	3	<C>
E	2	<E>
B	3	<C, B>

Note: At the end of round 2, each node has learned all two-hop paths

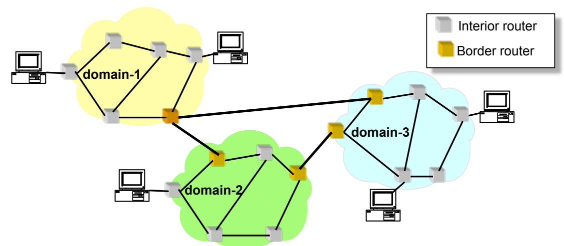
Questions About Path Vector

- How do we avoid permanent loops?
- What happens when a node hears multiple paths to the same destination?
- What happens if the graph changes?

Questions About Path Vector

- How do we ensure no loops?
  - When a node updates its paths, it never accepts a path that has itself
- What happens when a node hears multiple paths to the same destination?
  - It picks the better path (e.g., the shorter number of hops)
- What happens if the graph changes?
  - Algorithm deals well with new links
  - To deal with links that go down, each router should discard any path that a neighbor stops advertising

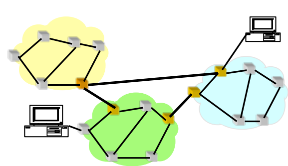
Hierarchical Routing



- Internet: collection of domains/networks
- Inside a domain: Route over a graph of routers
- Between domains: Route over a graph of domains
- Address consists of "Domain Id", "Node Id"

Hierarchical Routing

Advantage
- Scalable
  - Smaller tables
  - Smaller messages
- Delegation
  - Each domain can run its own routing protocol



Disadvantage
- Mobility is difficult
  - Address depends on geographic location
- Sup-optimal paths
  - E.g., in the figure, the shortest path between the two machines should traverse the yellow domain.

Routing: many open issues

- Misconfigurations between domains?
- Flat addresses and scalable?
- Routing in multihop WiFi networks?
- Routing in peer-to-peer networks?

Summary

- Protocols
- Layering of protocols
- Network layer: forwarding & Routing
  - Path-vector routing protocol