University of Glasgow

School of Computing Science

60 YEARS OF COMPUTING AT GLASGOW

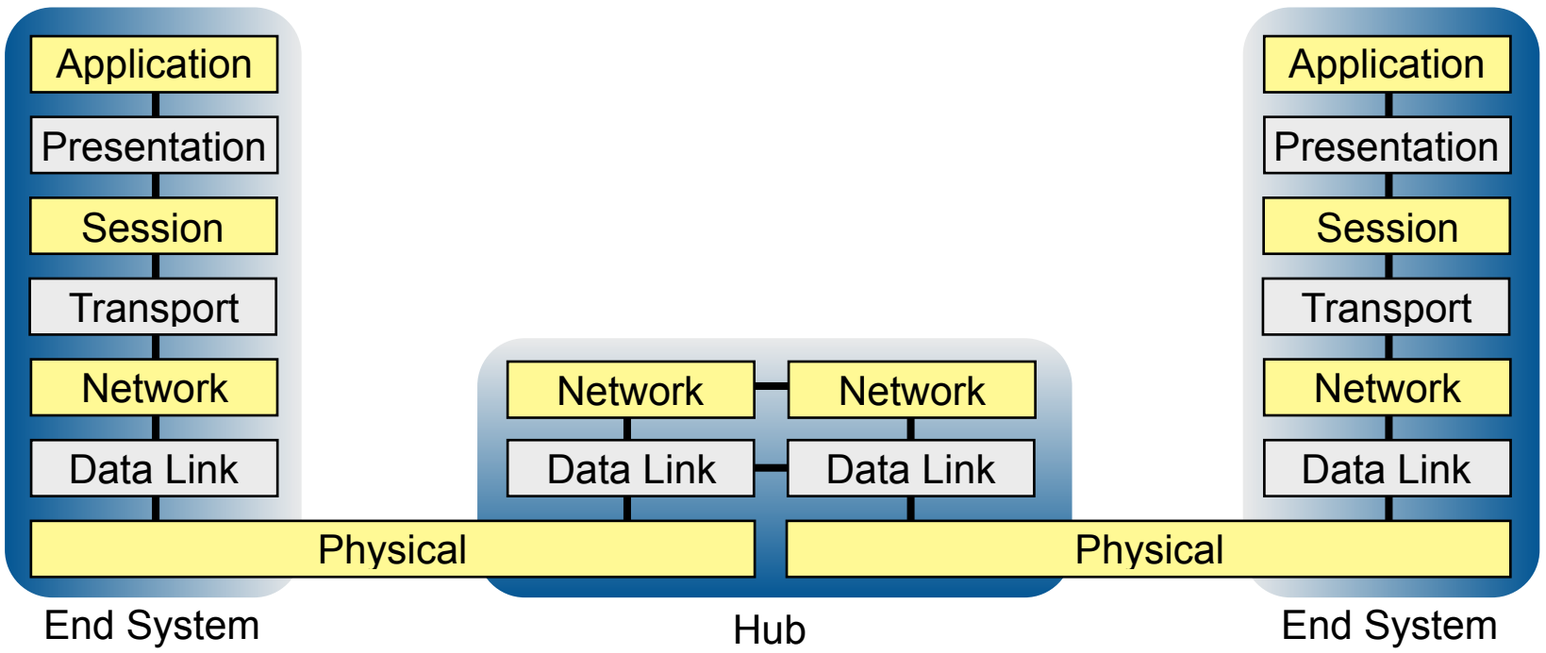
Internetworking

Networked Systems (H)

Lecture 7

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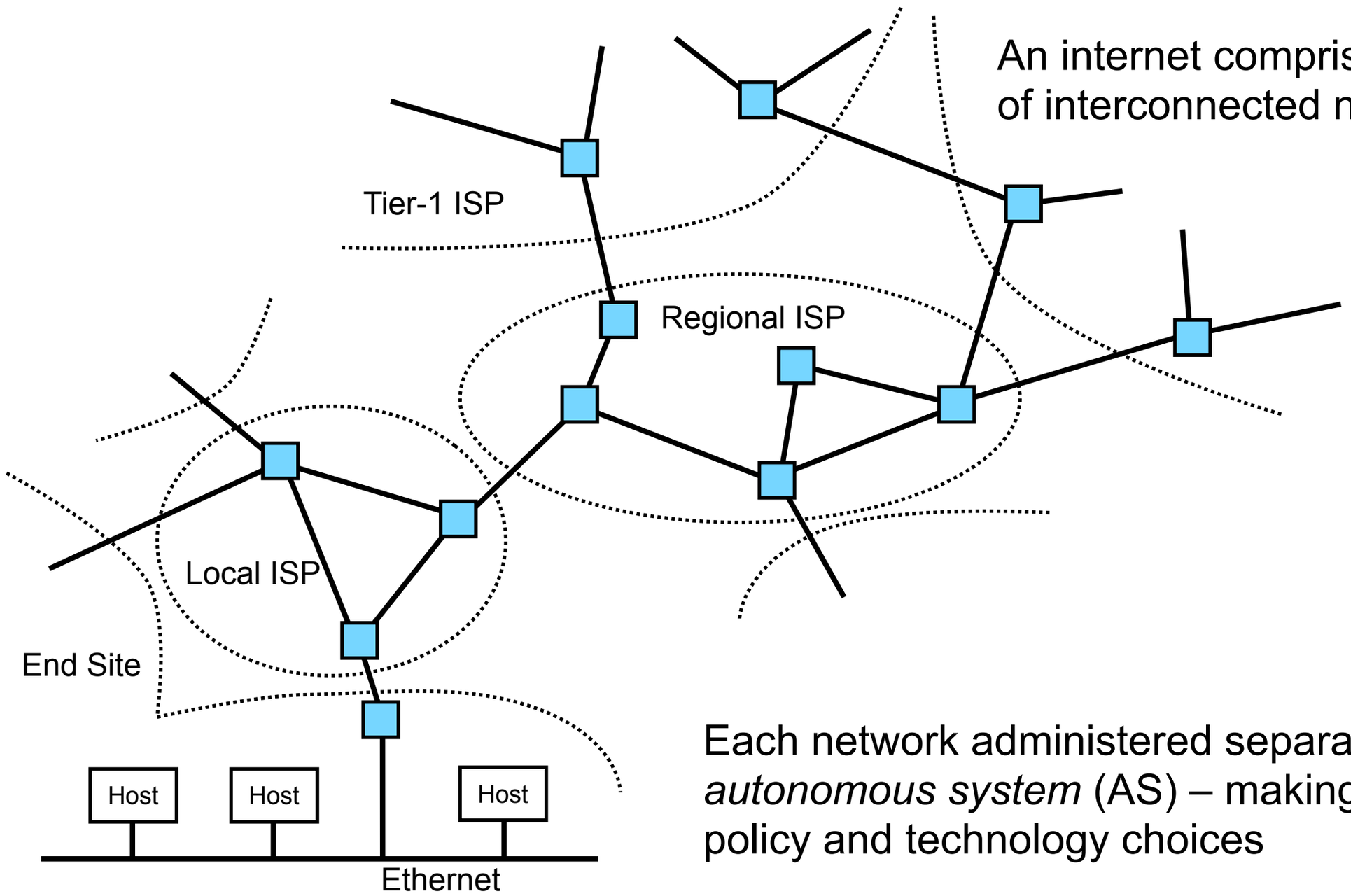
Role of the Network Layer



- Network layer is first end-to-end layer in the OSI reference model
- Responsible for end-to-end delivery of data:
  - Across multiple link-layer hops and technologies
  - Across multiple *autonomous systems*
  - Building an *Internet:* a set of interconnected networks

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Interconnecting Networks



Each network administered separately – an *autonomous system* (AS) – making independent policy and technology choices

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Components of an Internet

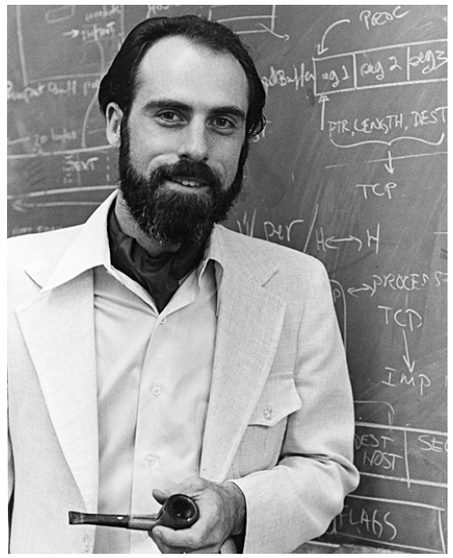
- A common end-to-end network protocol
  - Provide a single seamless service to transport layer
    - Delivery of data packets/provisioning of circuits
    - Addressing of end systems
- A set of gateway devices (a.k.a. *routers*)
  - Implement the common network protocol
  - Hide differences in link layer technologies
    - Framing, addressing, flow control, error detection and correction
    - Desire to perform the least amount of translation necessary

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The Internet

- The globally interconnected networks running the *Internet Protocol* (IP)
  - Initial design by Vint Cerf and Robert Kahn, 1974

- IP provides an abstraction layer
  - Transport protocols and applications above
  - Assorted data link technologies and physical links below
  - A simple, best effort, connectionless, packet delivery service
  - Addressing, routing, fragmentation and reassembly



Source: IEEE

Vint Cerf



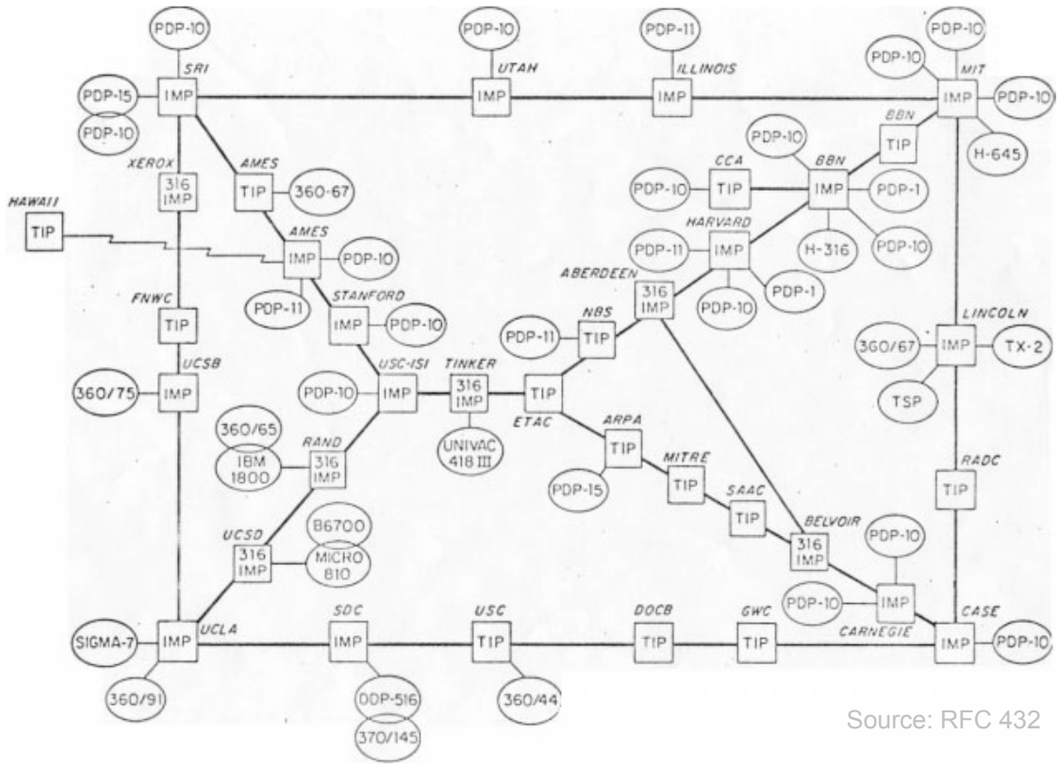
Source: IEEE

Robert Kahn

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History and Development

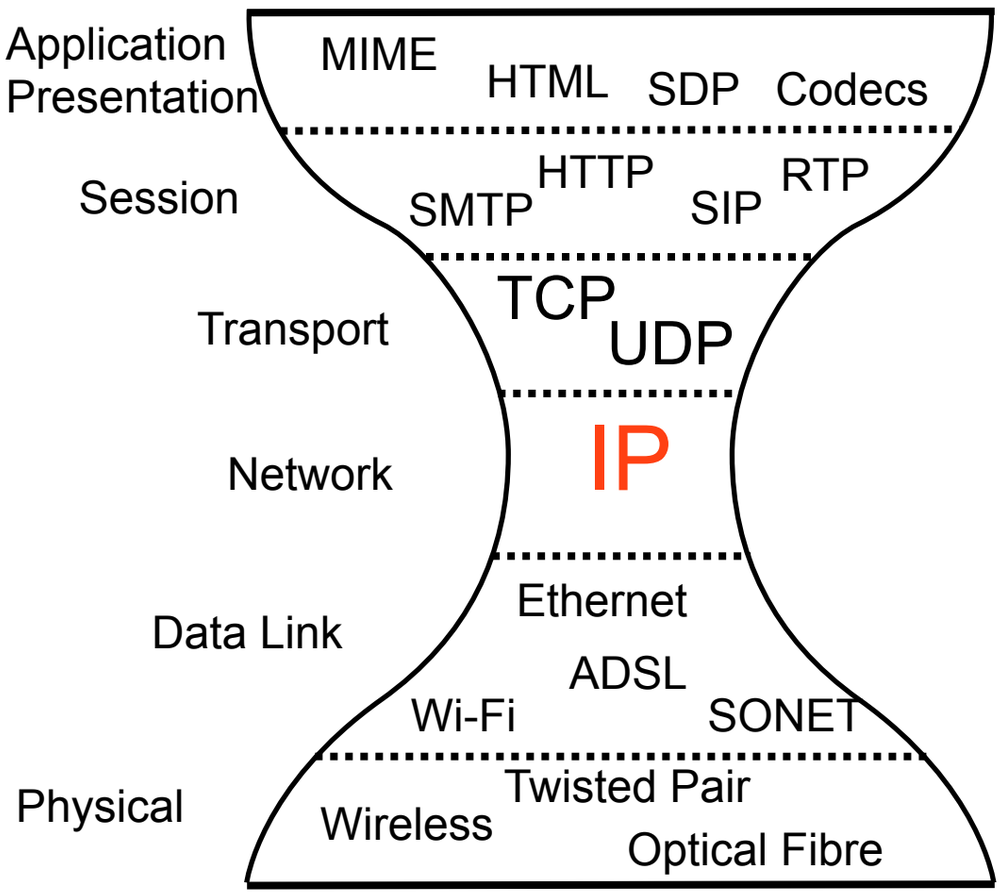
- 1965: Packet switching
  - Paul Baran (RAND), Donald Davies (NPL)
- 1969: ARPA funding
  - First link: UCLA – SRI
- 1973: First non-US sites
  - UCL, SICS
- 1983: Switch to IPv4
- 1990: World Wide Web
  - Tim Berners-Lee



ARPA network map, December 1972

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Basic Concepts



- Global inter-networking protocol
- Hour glass protocol stack
  - Single standard network layer protocol (IP)
    - Packet switched network, best effort service
    - Uniform network and host addressing
    - Uniform end-to-end connectivity (subject to firewall policy)
  - Many transport & application layer protocols
  - Range of link-layer technologies supported

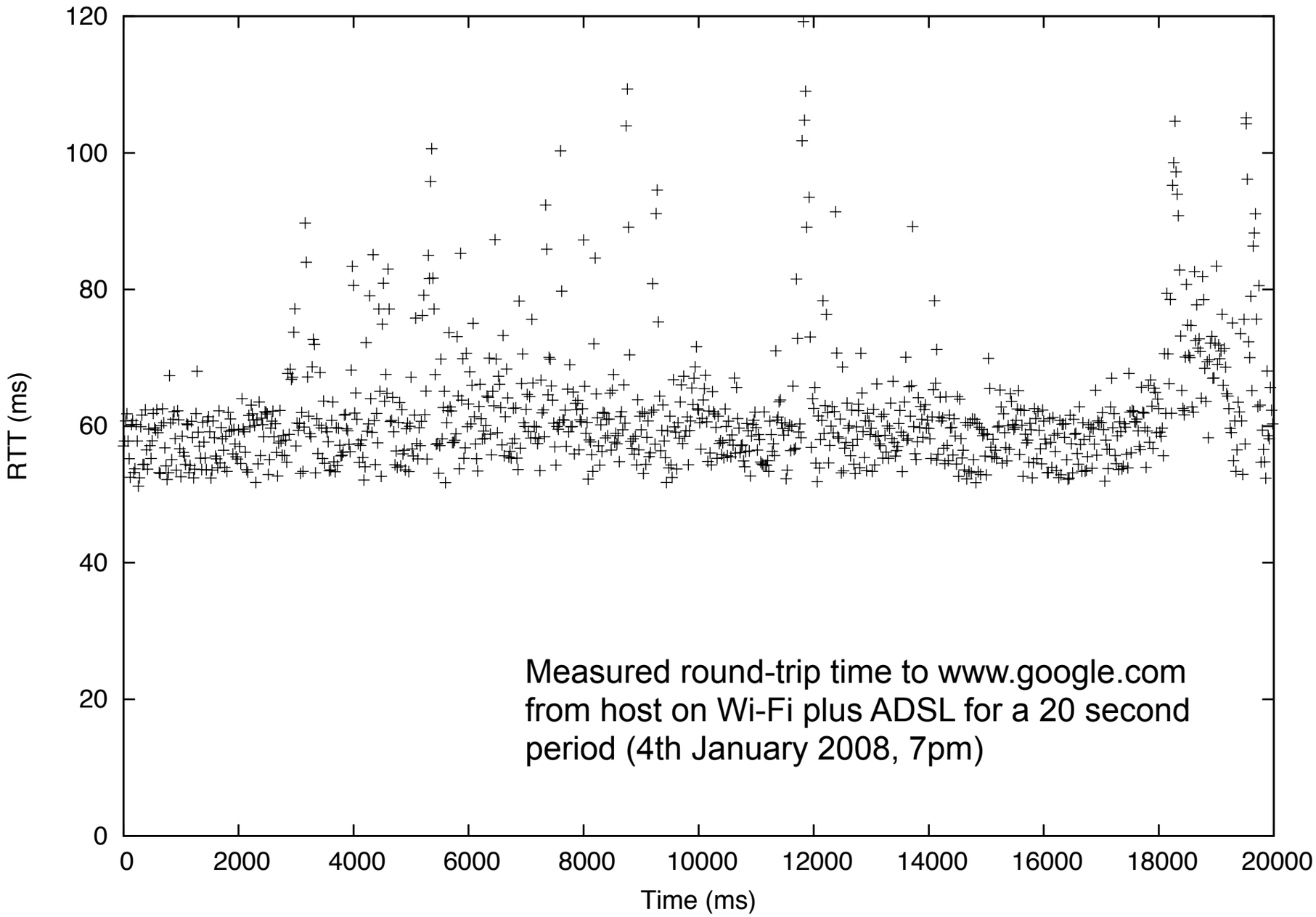
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IP Service Model

- Best effort, connectionless, packet delivery
  - Just send – no need to setup a connection first
  - Network makes its *best effort* to deliver packets, but provides no guarantees
    - Time taken to transit the network may vary
    - Packets may be lost, delayed, reordered, duplicated or corrupted
    - The network discards packets it can't deliver
  - Easy to run over any type of link layer
  - Fundamental service: can easily simulate a circuit over packets, but simulating packets over a circuit difficult

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Best Effort Packet Delivery



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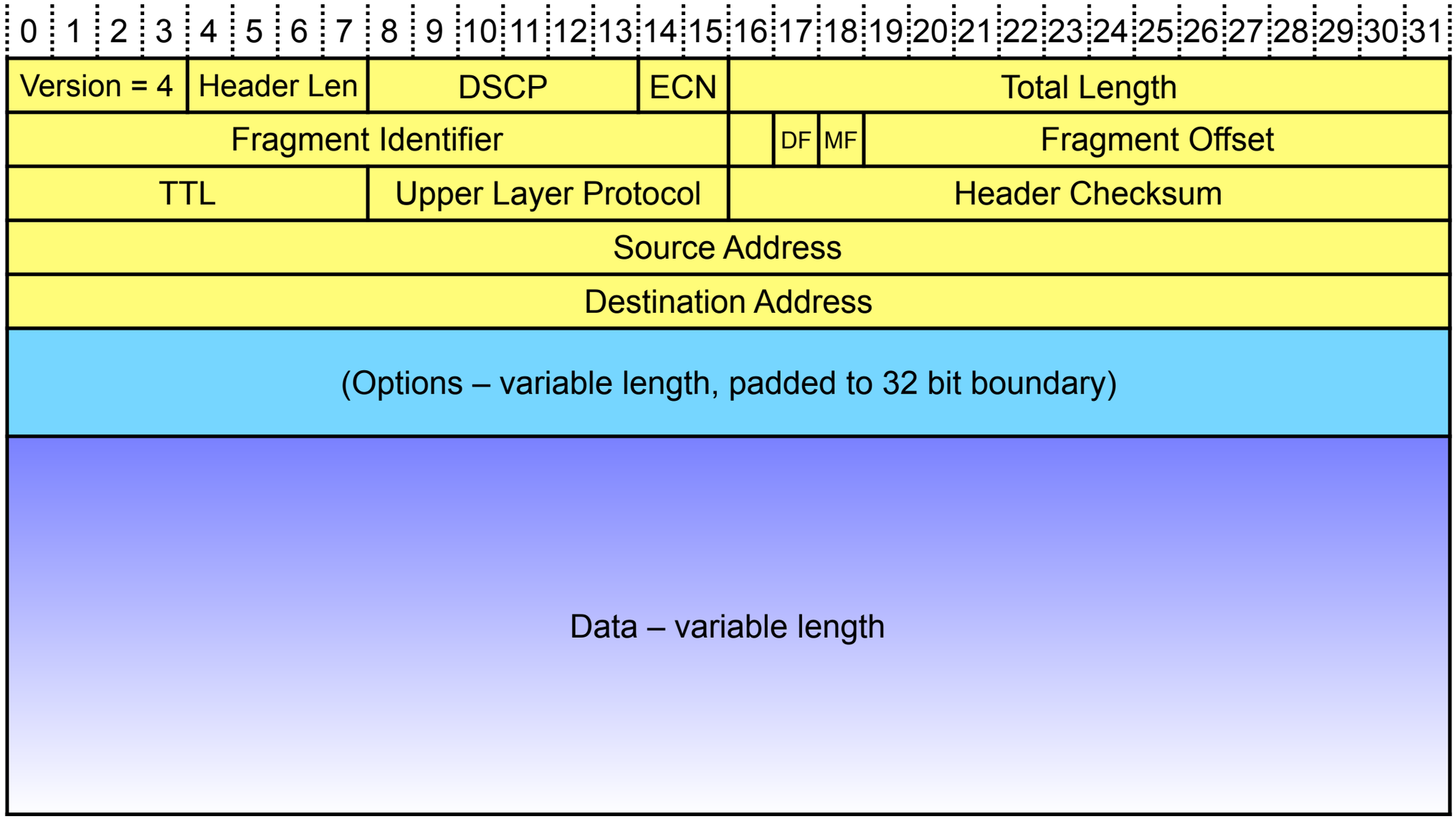
Internet Protocol

- Two versions of IP in use:
  - IPv4 – the current production Internet
  - IPv6 – the next generation Internet

  - IPv5 was assigned to the Internet Stream Protocol
    - An experimental multimedia streaming protocol developed between 1979 and 1995 [http://www.ietf.org/rfc/rfc1819.txt], but no longer used

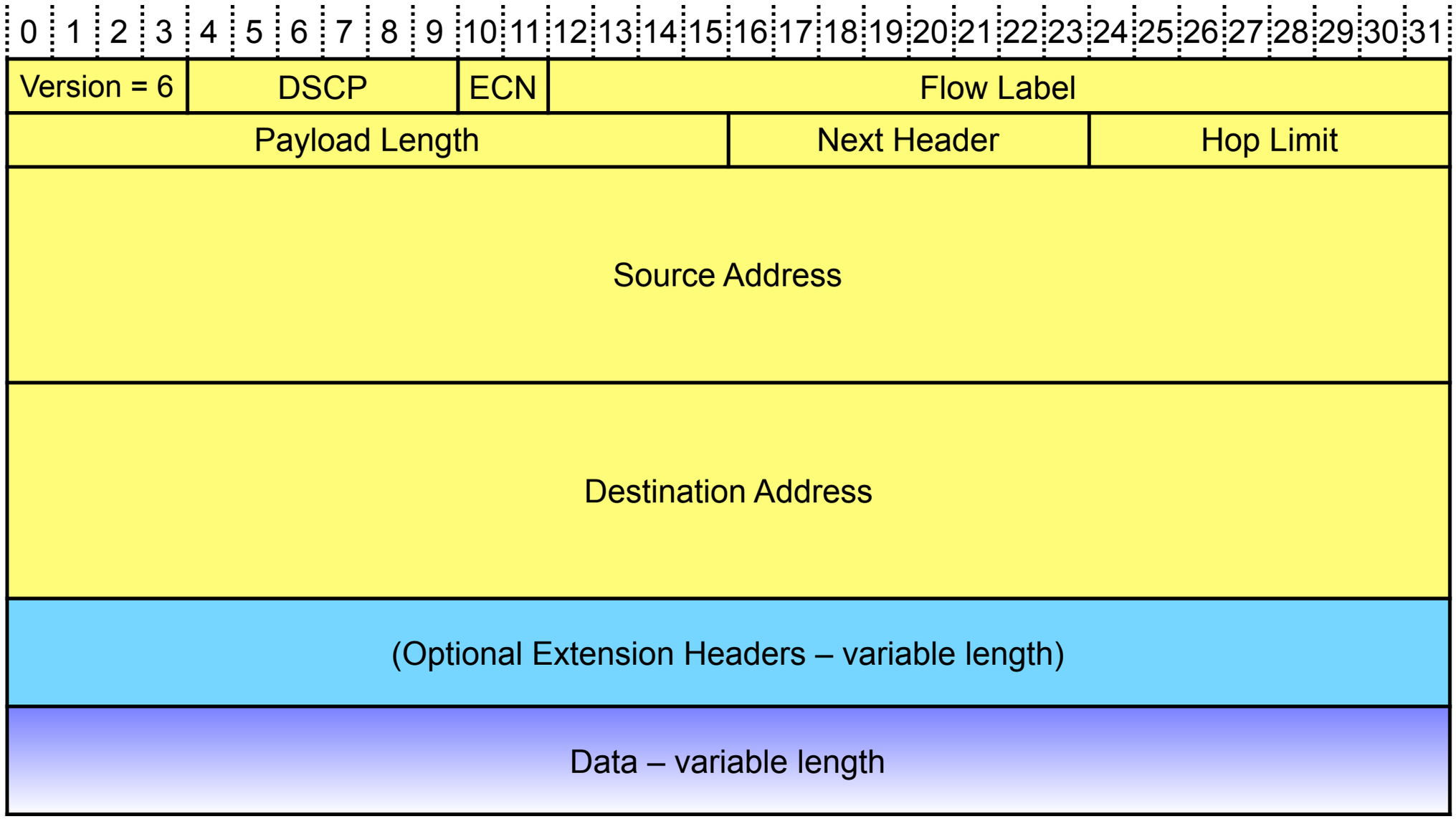
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IPv4 Packet Format



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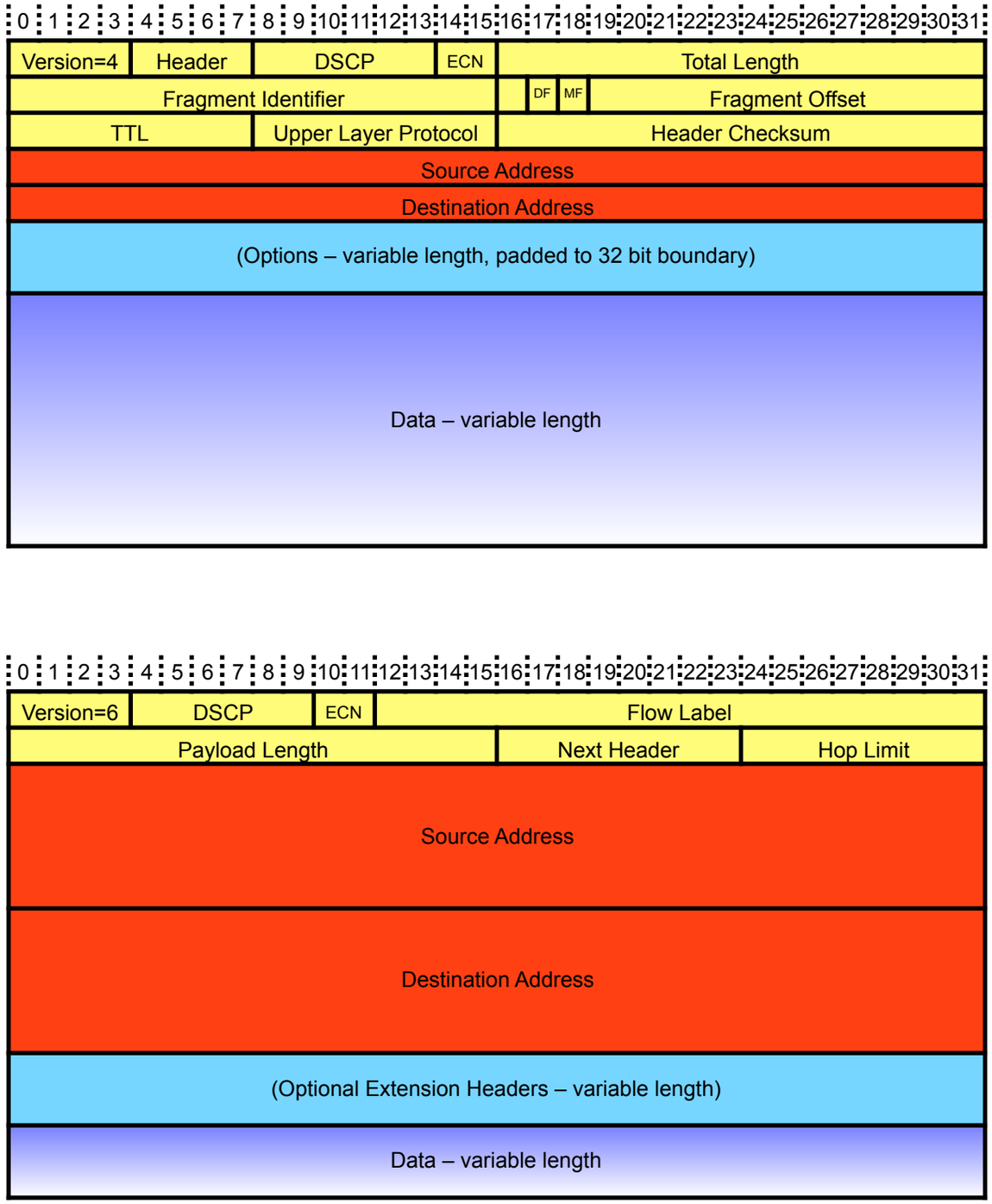
IPv6 Packet Format



Compared to IPv4: simpler header format, larger addresses, removes support for fragmentation, adds flow label

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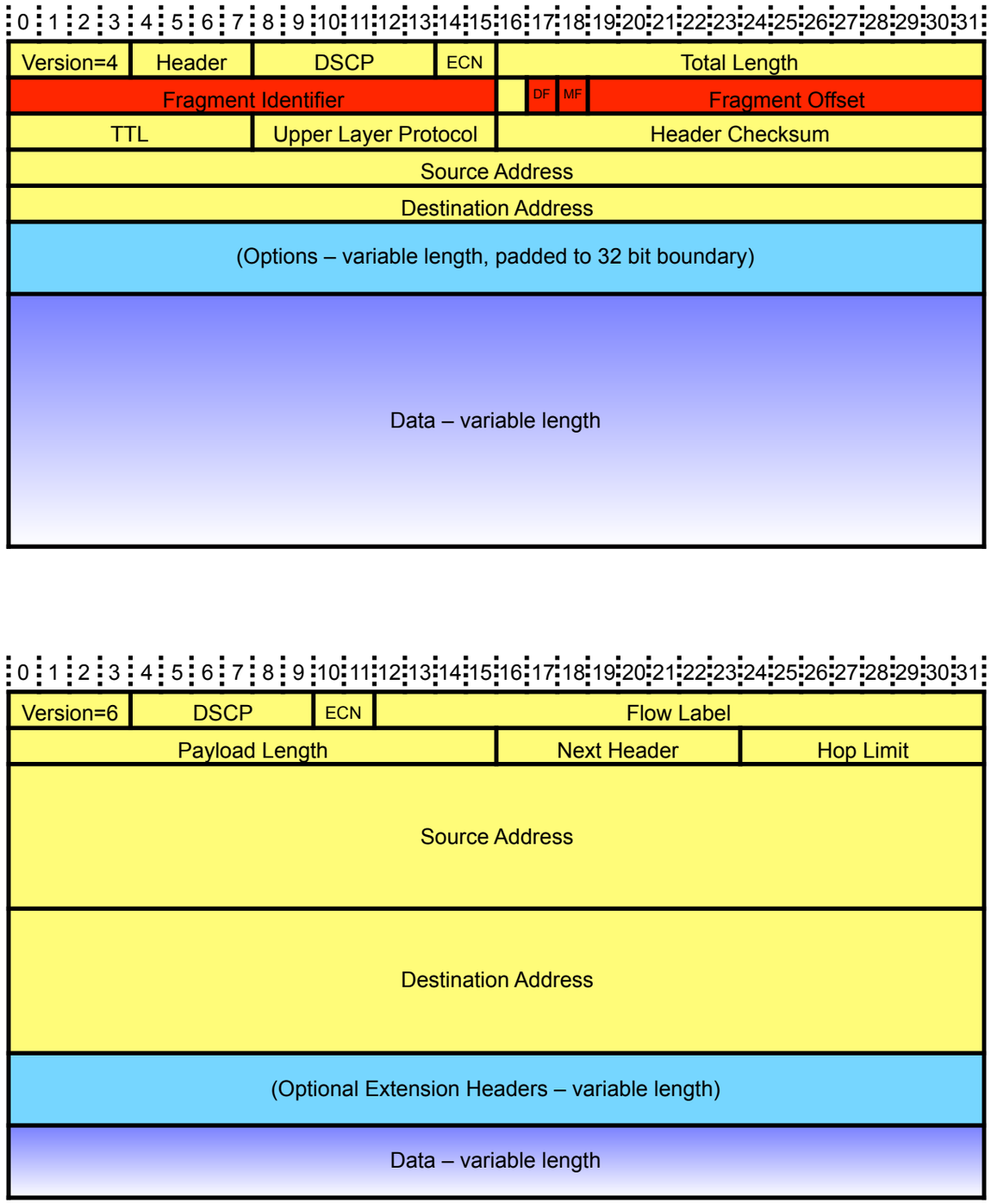
Addressing



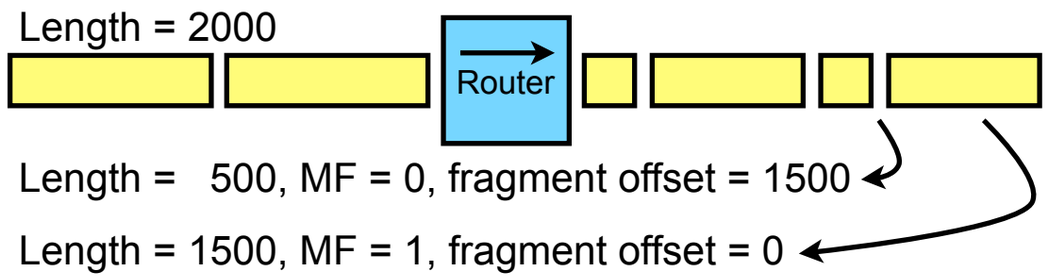
- Every network interface on every host is intended to have a unique address
  - Hosts may change address over time to give illusion of privacy
  - Addressable ≠ reachable: firewalls exist in both IPv4 and IPv6
- IPv4 addresses are 32 bits
  - Example: 130.209.247.112
  - Significant problems due to lack of IPv4 addresses → lecture 9
- IPv6 addresses are 128 bits
  - Example: 2001:4860:4860::8844

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Fragmentation



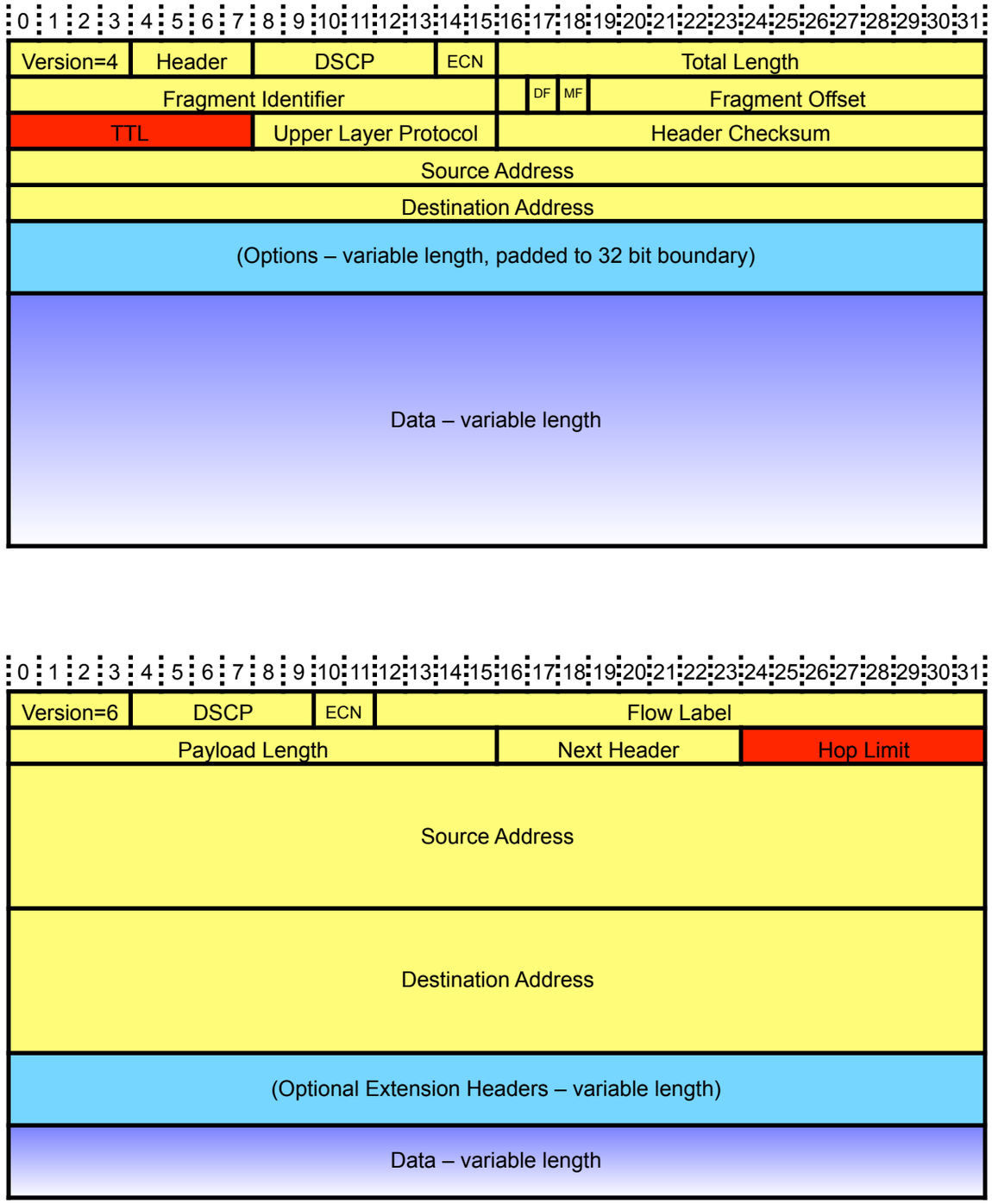
- Link layer has a maximum packet size (MTU)
- IPv4 will routers fragment packets that are larger than the MTU
  - MF bit is set if more fragments follow: reconstruct using fragment offset and fragment identifier



  - DF bit is set to indicate routers shouldn't fragment, and must discard large packets
- IPv6 doesn't support fragmentation
  - Hard to implement for very high rate links
  - End-to-end principle

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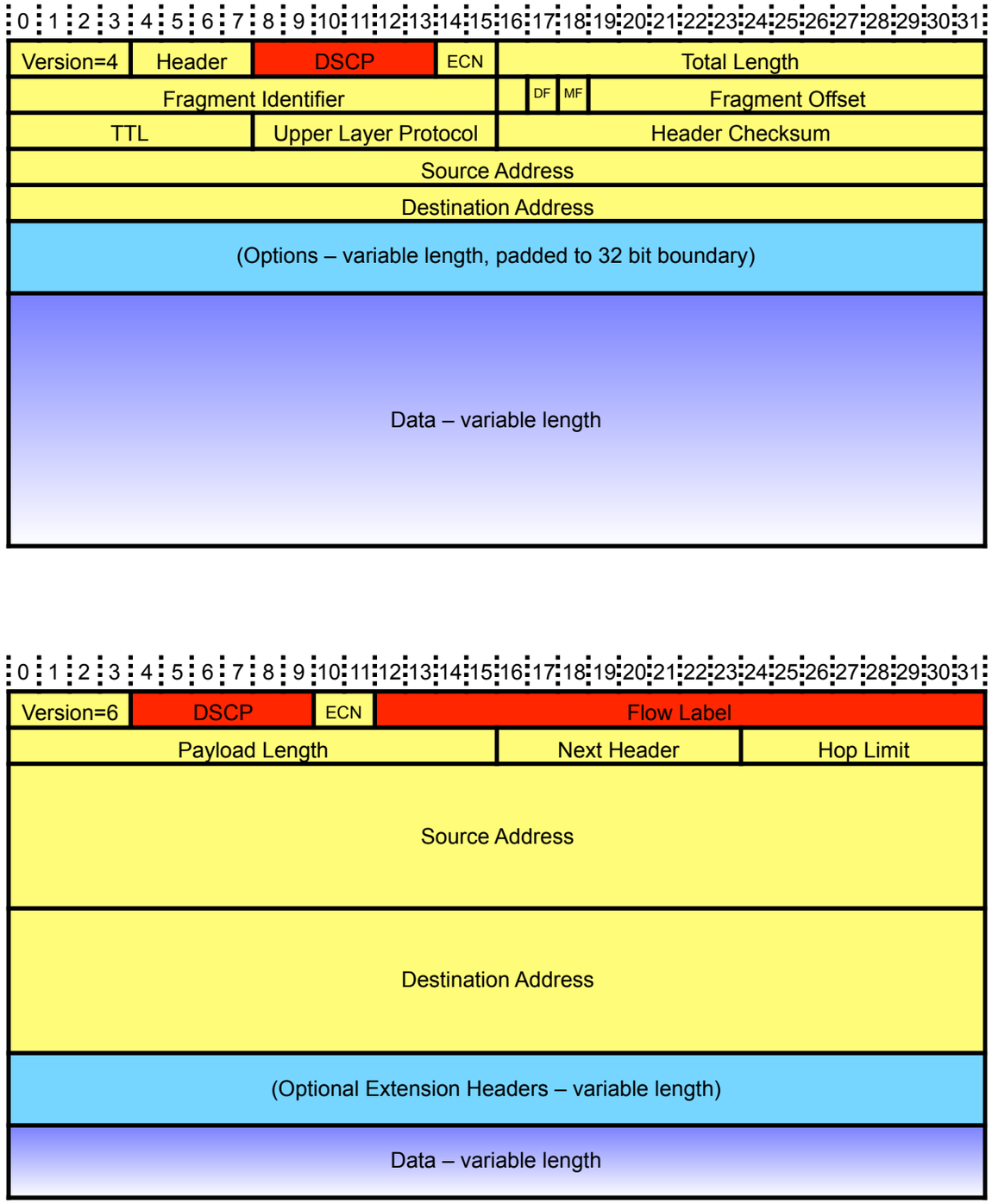
Loop Protection



- Packets include a forwarding limit:
  - Set to a non-zero value when the packet is sent (typically 64 or 128)
  - Each router that forwards the packet reduces this value by 1
  - If zero is reached, packet is discarded
- Stops packets circling forever if a network problem causes a loop
  - Assumption: network diameter is smaller than initial value of forwarding limit

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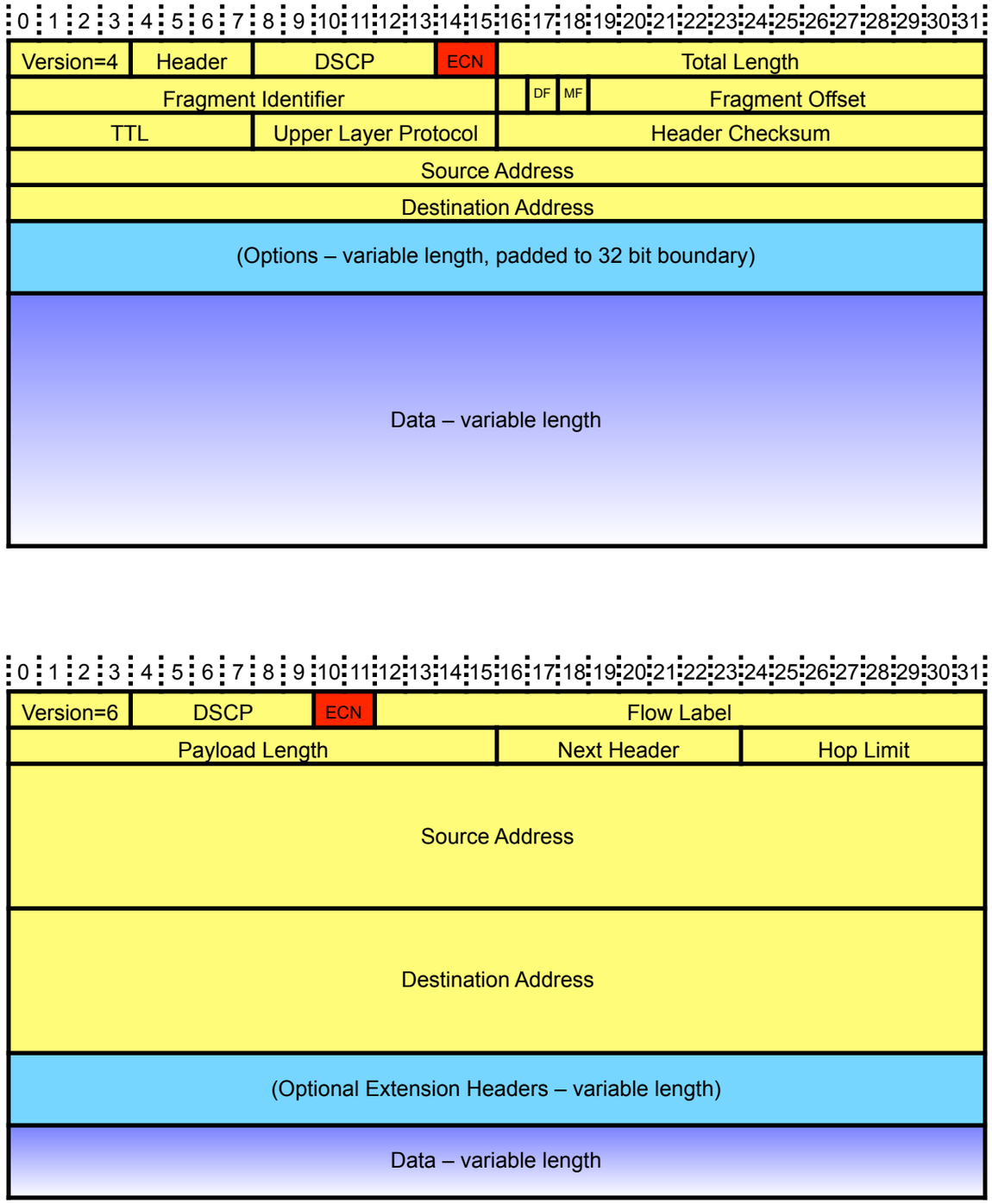
Differentiated Services



- End systems can request special service from the network
  - Telephony or gaming might prefer low latency over high bandwidth
  - Emergency traffic could be prioritised
  - Background software updates might ask for low priority
- Signalled by differentiated service code point (DSCP) field in header
- Provides a hint to the network, not a guarantee
  - Often stripped out at network boundaries
  - Difficult economic and network neutrality issues – who is allowed to set the DSCP and what are they charged for doing so?
- IPv6 provides a flow label to group related traffic flows together

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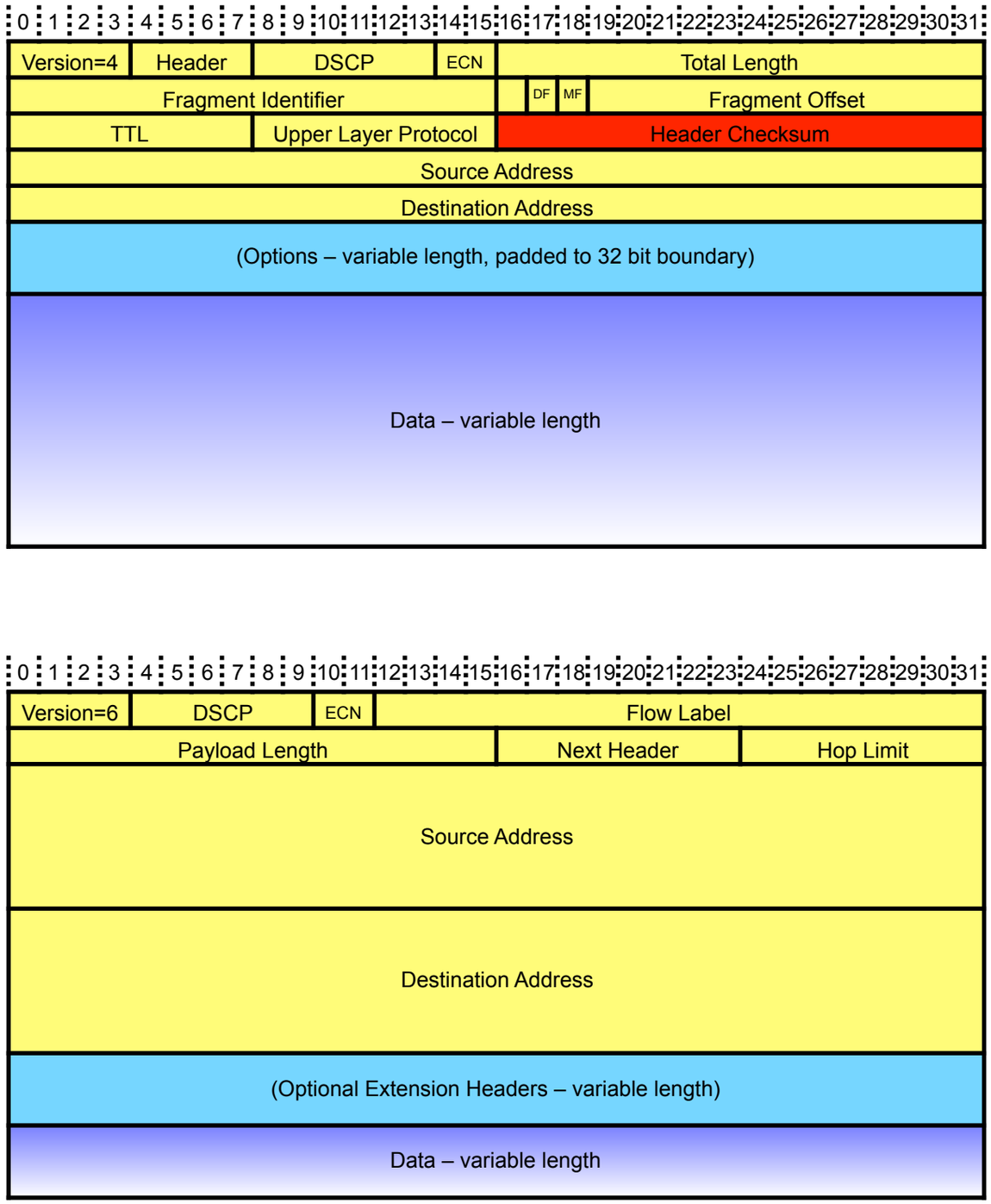
Explicit Congestion Notification



- Routers typically respond to network congestion by dropping packets
  - A “best effort” packet delivery service
  - Transport protocols detect the loss, and can request a retransmission if necessary
- Explicit congestion notification gives routers a way to signal congestion is approaching
  - If ECN=00 explicit congestion notification is disabled
  - If a sending host sets ECN=10 or ECN=01, routers monitor link usage, and can change the field to ECN=11 indicating congestion is imminent
  - A host receiving ECN=11 needs to reduce it’s sending rate – or the congested router will start dropping packets

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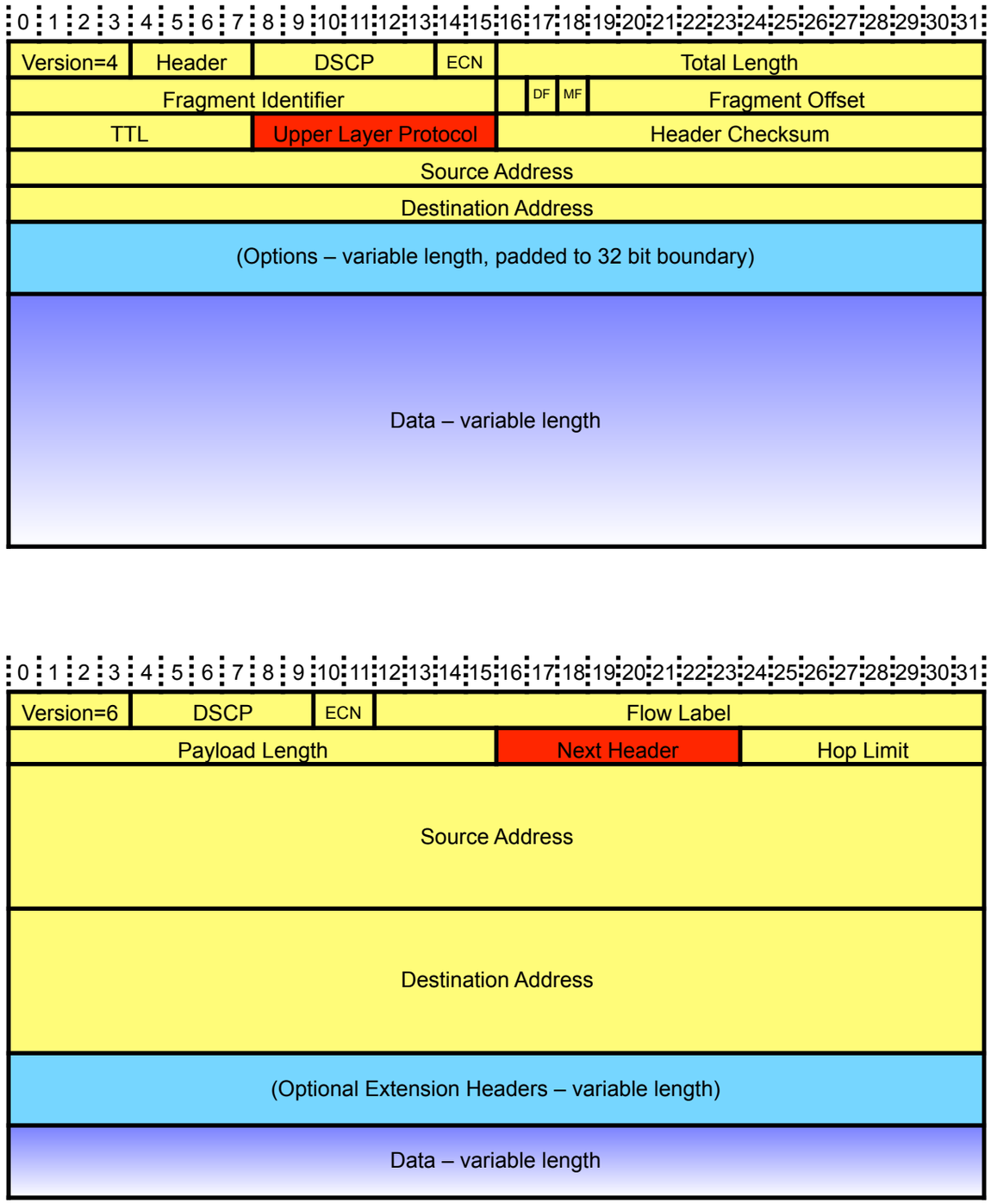
Header Checksum



- IPv4 header contain a checksum to detect transmission errors
  - Conceptually similar to link-layer checksum, although uses a different algorithm
  - Protects the IP header only, not the payload data protected (must be protected by upper layer protocol, if needed)
- IPv6 does not contain checksum – assumes the data is protected by a link layer checksum

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Transport Layer Protocol Identifier



- Network layer packet carry transport layer data as their payload
- Necessary to identify what transport protocol is used, to pass the data to the correct upper-layer protocol
  - TCP = 6
  - UDP = 17
  - DCCP = 33
  - ICMP = 1
- Legal values managed by the IANA
  http://www.iana.org/assignments/protocol-numbers/

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IPv4 or IPv6?

- IPv4 has reached end-of-life: insufficient addresses
- IPv6 intended as long term replacement for IPv4
  - Primary goal: increase the size of the address space, to allow more hosts on the network
  - Also simplifies the protocol, makes high-speed implementations easier
- Not yet clear if IPv6 will be widely deployed
  - But, straight-forward to build applications that work with both IPv4 and IPv6
  - DNS query using `getaddrinfo()` will return IPv6 address if it exists, else IPv4 address; all other socket calls use the returned value
  - Write new code to support both IPv6 and IPv4

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Summary

- Role of the network layer
- From *an* internet to *the* Internet
- Internet service model
- IPv4 and IPv6

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